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HOW THE NITROGEN PROBLEM HAS BEEN SOLVED.*

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INTRODUCTION.

THE enormous quantities of nitric acid and ammonia employed in the chemical industries and the nitrates used in agriculture were, until recently, obtained solely from the nitrate deposits in Chili, and from the destructive distillation of coal, these being the chief sources of inorganic nitrogen compounds. The world's total production of ammonia, calculated as ammonium sulphate, is one and one-half million tons per annum, while the present annual production of sodium nitrate is 3,120,000 tons.

In view of the ever-increasing demand for Chili saltpetre, some years ago estimates were made of the probable life of the Chilian deposits, and while these estimates vary considerably, it is evident that in a relatively short time the deposits will be exhausted. In addition to the nitrate beds in Chili, other deposits have been found in California, southeastern Oregon and in the Argentine, but the amount is either not very large or the deposits are situated in localities not easily accessible.

* Communicated by Professor Creighton.

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For some time there has been recognized the necessity of obtaining inorganic nitrogen compounds from other sources than those mentioned above. This necessity has been emphasized by the recent war. Attention naturally turned to the atmosphere, which has been estimated to contain four quadrillion tons of nitrogen, or twenty million tons over every square mile of the earth's surface. Unfortunately, however, before this inexhaustible supply of nitrogen can be used for industrial or agricultural purposes, it must first be converted into nitric acid, nitrates or ammonium compounds, forms in which nitrogen is most readily utilized.

During the past few years, much important research has been carried out on the transformation of atmospheric nitrogen into these forms—on the fixation of atmospheric nitrogen—and owing to the very fruitful results that have attended these labors, the practical solution of the nitrogen problem may be considered achieved. These investigations have led to the development of five different methods which may be broadly classed as follows:

I. The direct oxidation of nitrogen to its oxides with subsequent formation of nitric acid or nitrates, as exemplified in the Arc Processes;

II. The direct combination of nitrogen with hydrogen to form ammonia, as typified by the Haber Process;

III. The absorption of nitrogen by carbides, as developed in the Cyanamide Process;

IV. The absorption of nitrogen by metals in the form of nitrides, as represented by the Serpek Process;

V. The conversion of nitrogen into cyanides, as set forth in the Bucher Process.

At the present time the first three of these methods are successfully operated on a commercial basis. While, as yet, the Bucher process has scarcely passed beyond the experimental stage, it has been claimed that if the mechanical difficulties can be solved, ammonia will be produced more cheaply by this process than by either the Haber or Cyanamide processes.

The importance of these methods of nitrogen fixation in times of war, when the supply of Chili saltpetre may be cut off, is shown by the fact that Germany in 1914 produced 60,000 tons of nitric acid, in 1916, 300,000 tons and in 1917, 320,000 tons, from atmospheric nitrogen.

I. ARC PROCESSES.

OUTLINE OF THE PRINCIPLES UNDERLYING THE FORMATION OF NITRIC ACID FROM ATMOSPHERIC NITROGEN.

The conversion of atmospheric nitrogen into nitric acid is made up of several steps, which may be expressed by the following equations:

$$(1) \quad N_2 + O_2 \rightleftharpoons 2NO;$$
$$(2) \quad 2NO + O_2 \rightleftharpoons 2NO_2;$$
$$(3) \quad 2NO_2 + H_2O \rightleftharpoons HNO_3 + HNO_2.$$

Since, in the presence of oxygen, nitrous acid is rapidly oxidized to nitric acid, we may write:

$$(4) \quad 4NO_2 + O_2 + 2H_2O \quad 4HNO_3.$$

If instead of treating nitrogen peroxide with water, it is brought into contact with an aqueous solution of an alkali, nitrates and nitrites are formed.

The transformation of atmospheric nitrogen to nitric acid is by no means as simple as might appear from the above equations. The oxidation of nitric oxide to nitrogen peroxide is a reversible change: above 140° C., the latter commences to decompose into nitric oxide and oxygen, and this dissociation increases with rise in temperature until, at 620° C., it is practically complete. Therefore, between these two temperatures, the gas mixture consists of nitric oxide, nitrogen peroxide, oxygen and nitrogen (from the air). Since an equimolar mixture of the two oxides of nitrogen behaves towards aqueous solutions of alkali as if it were pure nitrogen trioxide, it is possible under proper conditions with these two gases to produce practically pure nitrite, in accordance with the equation:

$$(5) \quad N_2O_3 + 2NaOH = 2NaNO_2 + H_2O.$$

Many difficulties have been encountered in the oxidation of atmospheric nitrogen to nitric oxide. It has been found extremely difficult to obtain profitable yields of the oxide on passing an electric discharge through air, owing to the fact that the reaction expressed by equation (1) is reversible, and that, at even moderately high temperatures, the position of equilibrium is such that only small quantities of the oxide are formed. Since the formation of nitric oxide from its elements is an highly endothermic reaction (at ordinary temperature the formation of two

moles of nitric oxide is accompanied by the absorption of 43,200 gramme-calories), it follows in accordance with Le Chatelier's law that with rise in temperature the position of the equilibrium of the reaction will be displaced in the direction which favors the formation of the oxide. Starting with a given nitrogen-oxygen mixture, the concentration of nitric oxide present at equilibrium will be greater the higher the temperature. From a study of the reaction at lower temperatures, the concentrations of nitric oxide which would be present in the equilibrium mixture at higher temperatures have been calculated, and the values thus obtained have been found to be in good agreement with those determined by experiment, as shown by the data contained in Table I.

TABLE I.

Temperature ° C.	Volume per cent. of NO in equilibrium mixture.	
	Observed.	Calculated.
1538	0.37	0.35
1604	0.42	0.43
1760	0.64	0.67
1922	0.97	0.98
2307	2.05	2.02
2402	2.23	2.35
2627	....	3.18
2927	....	4.39

The close agreement between the two sets of values in Table I is a strong argument in favor of the reaction being a purely thermal one, although evidence has been brought forward which supports the view that temperature is not the only factor which influences the reaction.

Since the velocity of all chemical reactions increases with temperature, it is evident that in order to produce nitric oxide successfully from nitrogen and oxygen, it will be necessary to work, not only at a temperature at which an appreciable amount is formed, but also at a temperature at which its formation takes place rapidly. The influence of temperature on the velocity of the formation of nitric oxide is illustrated by the data contained in Table II.

The values in the last column of Table II show that while at even as high a temperature as 1227° C. the rate of formation of nitric oxide from its constituents is so slow as to be negligible, it

is produced instantaneously at temperatures above 2227° C. On the other hand, the times required for the *decomposition* of one-half of a given quantity of nitric oxide are 7.35×10^3 minutes at 627° C., 5.80×10^2 minutes at 827° C., 3.30 minutes at 1227° C., and 1.21×10^{-3} minutes at 1827° C. It is evident from these figures that at temperatures below 827° C. the rate of decomposition of nitric oxide into its constituents is so slow as to be negligible in practice.

From the preceding data, it is obvious that a very high temperature is essential for the formation of nitric oxide in even moderately small quantities. The most convenient means of producing this high temperature is the electric arc, and this is the only method which thus far has met with success. Moreover,

TABLE II.

Temperature ° C.	Time required for the formation of one-half the theoretical nitric oxide concentration at atmospheric pressure.	
	Minutes.	
1227	1.81×10^3	(1.26 days)
1427	5.90×10	
1627	2.08	
1827	8.43×10^{-2}	(5.06 seconds)
2027	3.75×10^{-3}	
2227	1.77×10^{-4}	(0.01 second)
2427	8.75×10^{-5}	
2627	5.75×10^{-6}	(0.000035 second)
2827	3.10×10^{-8}	

although it has been assumed that the efficacy of the electric arc is due to its high temperature, still the observations of a number of investigators indicate the probability of purely electrical influences playing a part in the formation of nitric oxide in the electric discharge.

At any rate, whatever be the action of the arc, even under the most favorable conditions only a few per cent. of nitric oxide is produced when equilibrium sets in. Consequently, in order to convert large quantities of nitrogen and oxygen into nitric oxide, it is necessary to remove the latter from the sphere of the action of the arc as fast as it is formed. In this way the attainment of equilibrium is prevented and the process becomes continuous. Since, as has just been pointed out, the rate of decomposition of nitric oxide into its constituents is very rapid at high tempera-

tures, and negligibly slow for all practical purposes at temperatures below 827° C., it is necessary to quickly and efficiently cool the gas mixture after removing it from the action of the arc, in order to preserve a high concentration of the oxide. The more rapid the cooling, the less the decomposition of the oxide formed at the high temperature of the arc. An idea of the temperature of the gas mixture in the arc may be gained from the fact that, with high tension arcs, concentrations of nitric oxide as high as eight volume per cent. have been obtained. This concentration corresponds to a temperature of 3700° C.

Many investigations have been carried out for the purpose of increasing the concentration of the nitric oxide formed in the arc, and it has been found that this is influenced by the rate of flow of the nitrogen and oxygen through the arc, and by the proportion of these elements in the initial gas mixture. Thus Grau and Russ, using high tension arcs, found that with a high velocity of flow of the gases through the arc the concentration of nitric oxide formed was small, while with diminishing velocity the concentration increased. These investigators found, when operating at 2300–2600 volts and 175 watts, that the nitric oxide concentration produced was 2.90 volume per cent. when the flow of air through the arc was 104.1 liters per hour, and 4.181 volume per cent. when the flow was reduced to 30.9 liters per hour. The equilibrium concentration of nitric oxide in the arc was calculated by extrapolation for zero velocity. This gave 5.5 volume per cent. from air, and 6.6 volume per cent. from a mixture containing equal volumes of nitrogen and oxygen, these quantities being independent of the length of the arc. The nitric oxide concentration may also be increased by allowing the air after passing through the arc to mix with the unarced gas. It has been suggested that these conditions are favorable to the formation of ozone, and that it is the oxidation of the nitrogen by the ozone that brings about an increase in the oxide concentration.

After the formation of nitric oxide in the arc, the next step in the production of nitric acid is its oxidation to nitrogen peroxide. This may be brought about by the oxygen contained in the air which escaped combustion in the arc. Since nitrogen peroxide, as already pointed out, commences to break up into nitric oxide and oxygen at 140° C., and is completely dissociated at or above 640° C., it is evident that until the temperature of the gas

mixture, after removal from the arc, falls below the latter temperature, no peroxide will be formed; and until the temperature is reduced below 140° C., the gas mixture will contain both oxides of nitrogen. If the cooled gas mixture is passed into water the nitrogen peroxide is converted into nitric and nitrous acids, in accordance with the reaction expressed in equation (3). As the nitrous acid readily changes into nitric acid:

$$(5)\quad 3HNO_2 \rightleftarrows HNO_3 + 2NO + H_2O,$$

the total reaction may be expressed by the equation:

$$(6)\quad 3NO_2 + H_2O \rightleftarrows 2HNO_3 + NO.$$

Since the reactions expressed by equations (3) and (5) are reversible, the equilibrium of the latter and, therefore, that of the former is distributed by the subsequent oxidation of the nitric oxide liberated in (5), *i. e.*,

$$(7)\quad 2NO + O_2 \rightleftarrows 2NO_2,$$

and, consequently, a given quantity of nitrogen peroxide must be ultimately transformed into nitric acid.

When a mixture of nitrogen peroxide and oxygen is led into water, nitric acid is formed rapidly until its concentration reaches about 40 per cent.; the absorption then gradually becomes slower until a concentration of 50 per cent. is attained, above which the rate of absorption rapidly diminishes. The concentrations of nitric acid obtained at ordinary temperatures from gas mixtures containing different quantities of nitrogen peroxide are as follows:

Concentration of Nitrogen peroxide.	Limiting Concentration of nitric acid obtained.
Volume per cent.	Per cent.
1	ca 46
2	ca 52
5	55

Since, technically, the cooled gases from the arc usually contain from 1–2 per cent. of nitrogen peroxide, it should be possible to produce aqueous nitric acid having a concentration of about 50 per cent. by treating the gas mixture with water. If, as previously mentioned, the hot gas mixture, containing both nitric oxide and nitrogen peroxide, is treated with an aqueous alkali solution, the nitrate and the nitrite of the alkali metal will be formed, the latter predominating the higher the temperature at which absorption takes place.

A few figures regarding the consumption of electrical energy

in the production of nitric acid by the arc process may be of interest. Haber has calculated that the theoretical yield of nitric acid is 134 grammes per kilowatt hour or 1174 kilogrammes per kilowatt year, at 4200° C., and 93.5 grammes per kilowatt hour or 819 kilogrammes per kilowatt year at 3200° C. While the yield of acid is smaller at the lower temperature, it must be remembered that in practice there is a smaller loss of nitric oxide due to decomposition during the period of cooling, and a smaller loss of heat by radiation. Technical yields of nitric acid are always less than those indicated by the above figures.

On account of the small yields of nitric acid in the arc process, cheap power must be available in order to produce the acid profit-

TABLE III.

Locality.	Total costs or charges per kilowatt year to large consumers.
Niagara*	$22.40–$26.60
Niagara (Ontario Power Co. to Municipalities)*	$13.60
Sault Ste. Marie *	$13.30
Cameron Rapids, Ontario	$11.00
Kootenay Power Co	$32.00
Kanawa Falls, Virginia	$12.80
Svaelgfos, Norway	$ 2.64
Notodden, Norway	$ 4.33
Sweden	$4.16–$9.60
Austria (Meran)*	$15.20
Savoy (Bellegrade)*	$14.10
Savoy (Chedde)	$ 5.87

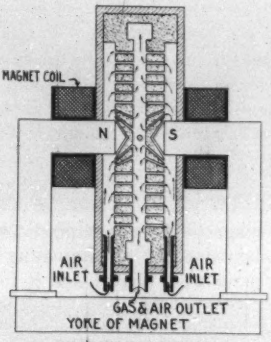
ably by the method that has been outlined; and it is chiefly in Norway and the Alpine countries, where there are large quantities of cheap water power that, up to the present, atmospheric nitrogen has been converted into nitric acid on a commercially successful scale by the arc process. Assuming that one kilogramme of combined nitrogen has a market value of twenty-five cents, then on the basis of electric power at the rate of $10 per kilowatt year, a technical yield of 60 grammes of nitric acid per kilowatt hour pays for the power three times over. The variation in the cost of water power in a number of different localities is shown by the data[1] given in Table III (the asterisk denotes prices at which the power is actually sold).

[1] Lucke, C. E., *Electrochem. and Met. Ind.*, 6, 230 (1907).

With respect to the power which is being developed at Muscle Shoals, Tennessee, United States Army engineers have placed the cost between $9 and $12 per kilowatt year or about 1.5 mills per kilowatt hour.

Another source of cheap electrical power is off-peak power, which, it has recently been claimed,[2] can be secured in many places in the United States at a lower cost than Norwegian power.

FIG. 1.



BIRKELAND-EYDE FURNACE.

TECHNICAL FURNACES FOR THE PRODUCTION OF NITRIC OXIDE FROM AIR.

Of the different furnaces that have been devised for the oxidation of nitrogen in the electric arc, only a few have been successful. Of the latter the most important are the Birkeland-Eyde furnace, which is used in Norway, France and Spain; the Schönherr furnace, which is employed in Norway and Germany; and the Pauling furnace, which is operated in Italy, Austria and Germany. In addition to these, the Moscicki and the Kilburn Scott furnaces should be mentioned.

(*a*) *The Birkeland-Eyde Furnace.*

The Birkeland-Eyde furnace, a vertical section of which is shown in Fig. 1, has the appearance of a large cylinder resting on

[2] Steinmetz, C. P., *et al.*, Proc. Am. Inst. Elec. Eng. (1918). Advance copy.

its side between the poles of a huge electro magnet (Fig. 2). This cylinder is made of two similar halves of heavy cast iron plates (Fig. 3), which are bolted together. The interior of the furnace is lined with refractory material perforated with numerous small openings through which the air enters the narrow, circular reaction chamber situated in the centre. A peripheral channel in the casting of the furnace serves to carry away the nitrous gases from the reaction chamber. The large terminal poles of the electro magnet are bevelled and are imbedded in the lining of the furnace. The coils of the magnet, placed immediately outside of the iron shell, are fed by a direct current and absorb 0.35 to 1 per cent. of the total furnace load. The thick, water-cooled tubular, copper electrodes, supported on ball insulators, enter the reaction chamber through opposite sides of the furnace, their internal ends being separated by a distance of one centimetre. The cooling effect of the electrodes causes a loss of only about 7.5 per cent. of the electrical energy.

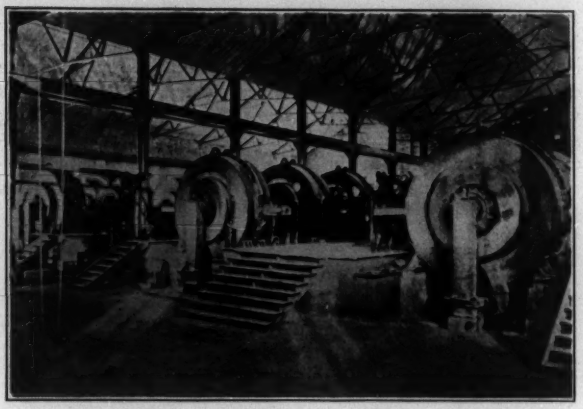
The positions of the electrodes and the poles of the magnet are such that the magnetic field is perpendicular to that of the arc. The arc is maintained by an alternating current of about 5000 volts and 50 periods per second, and is forced by the magnetic field into two semi-circular discs of flame (Fig. 4) which alternately rise and break in the lower and upper half of the reaction chamber, producing what appears to be a thin, circular sheet of flame 1.8 metres in diameter that burns with great steadiness.

The air on entering the reaction chamber impinges on the flame at right angles, where it is partially oxidized to nitric oxide. Notwithstanding the very high temperature of the arc (over 3000° C.), that of the nitrous gases on leaving the reaction chamber is between 800° C. and 1000° C., while the temperature of the refractory lining seldom exceeds 700° C., due to the cooling effect of the air current.

The capacity of the Birkeland-Eyde furnace has increased from 300 kilowatts in 1906 to 4000 kilowatts at the present time.

The most striking features of this furnace are its simplicity and durability. It burns for weeks with scarcely any regulation. It is only necessary to change the electrodes every three or four weeks and the refractory lining every four to six months. A few workmen are able to operate a large number of these furnaces.

FIG. 2.



BIRKELAND-EYDE FURNACES AT NOTODDEN, NORWAY.

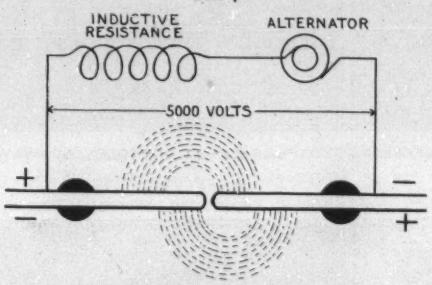
FIG. 3.

BIRKELAND-EYDE FURNACE.

(*b*) *The Schönherr Furnace.*

This furnace differs in principle from the one just described, in that, in place of the circular sheet of flame, a long, slender arc is developed in the narrow axis of an iron tube, through which a current of air is forced. The arc is stabilized by imparting a whirling motion to the air. In this furnace the air passes along and surrounds the arc with which it is in contact for an appreciable time, whereas in the Birkeland-Eyde and Pauling (described below) furnaces the air, entering at right angles to the electric discharge, is in contact with the arc for an exceedingly short time.

FIG. 4



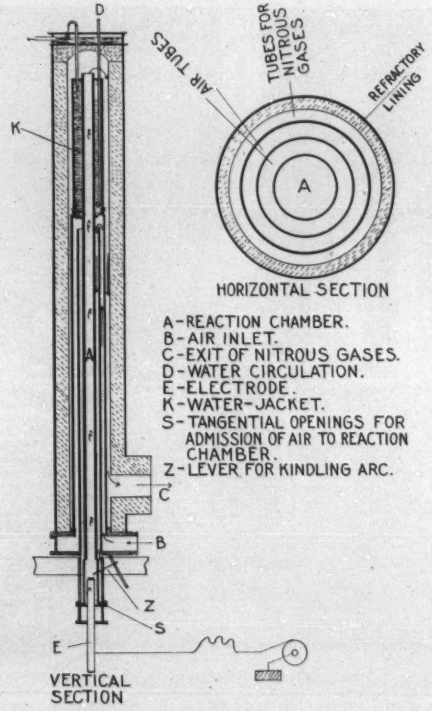
DIAGRAMMATICAL REPRESENTATION OF THE DISPLACEMENT OF THE SEMICIRCULAR ARCS IN BIRKELAND-EYDE FURNACE.

The Schönherr furnace, cross-sections of which are shown in Fig. 5, consists of a vertical cylinder of iron plate, 23 feet in height, lined with refractory material. In the centre are placed three concentric wrought iron tubes. The inner tube, A, is six inches or less in diameter and constitutes the reaction chamber. The other tubes form passages through which the air enters and through which the nitrous gases pass from the reaction chamber after being in contact with the arc. By means of this arrangement, a large portion of the heat of the out-going gases is transferred to the in-coming air. The path traversed by the gases is indicated by the arrows in Fig. 5.

The air enters the reaction chamber through a number of

tangential openings so arranged at its base that there is imparted to it a pronounced vortical motion. This motion is sufficiently strong to maintain a material difference in pressure between the

FIG. 5.

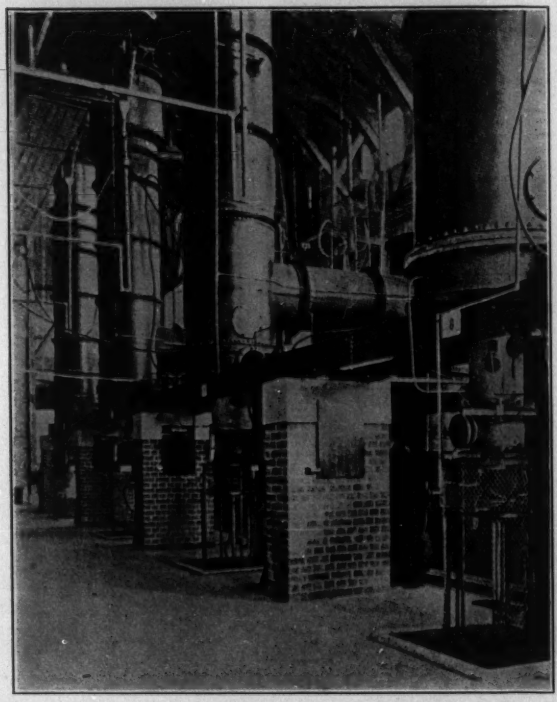


SCHÖNHERR FURNACE.

axis of the vortex occupied by the arc, and the outer sections of the air current. The admission of the air to the reaction chamber is controlled by a lever. The upper third of the reaction chamber is surrounded by a water jacket, K. The nitrous gases leave the

reaction chamber at a temperature of about 1200° C., and on passing through the furnace transmit to the in-coming air sufficient heat to raise its temperature to about 500° C.

FIG. 6.

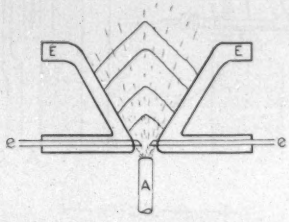


SCHÖNHERR FURNACES AT KRISTIANSAND.

An iron bar, E, situated at the lower end of the reaction chamber, serves as the main electrode. This bar is movable in a vertical direction through an opening in the hollow, water-cooled, copper terminal of the electric current. This electrode projects a

little above the surface of the terminal, and is so arranged that it can be moved upwards by a cog mechanism as it is worn away by the action of the arc. The rate of wear is about twenty millimetres daily. The reaction chamber, in direct connection with the other metallic parts of the furnace, serves as the second electrode. The lever Z is used to start the arc, which when once kindled is rapidly drawn upwards by the air current, the vortical motion of which maintains a slender, rod-like flame which occupies the axis of the reaction chamber throughout its length. The flame only comes in with the reaction chamber at its upper extremity which is cooled by the top portion of the water-jacket, K.

FIG. 7.



ELECTRODES OF PAULING FURNACE.

Owing to the fact that the length of the reaction chamber is governed by the voltage, and also that there is a limit to the current that can be dealt with by a single electrode, the capacity of the Schönherr furnace is restricted to 1000 kilowatts (Fig. 6).

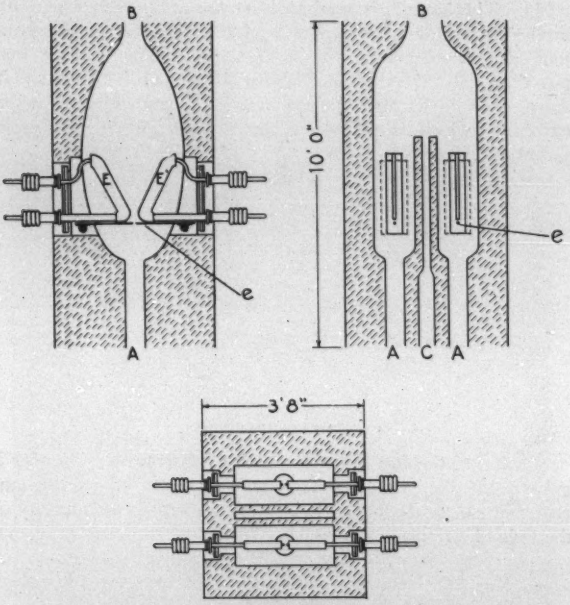
The Schönherr furnace requires considerable attention, on account of the frequency with which the arc is extinguished, rekindling having to be done by hand.

(*c*) *The Pauling Furnace.*

In the Pauling furnace the arc is formed between hollow, water-cooled electrodes, E (Fig. 7), set at an angle of about 80°, and which, at their lowest point, are slightly over one and one-half inches apart, so as not to interfere with the air blast from the supply pipe, A. Very thin kindling blades, *e*, passing through the curved part of the main electrodes, are employed to start the arc which is maintained with a high tension alternating

current. As soon as the arc is formed, it is forced by the air blast from A upwards along the inclined electrodes. At each half period a new arc is kindled, so that, with rapid alternations of the current, a sheet of flame is produced which fills the space

FIG. 8.



VERTICAL AND HORIZONTAL SECTIONS OF THE PAULING FURNACE.

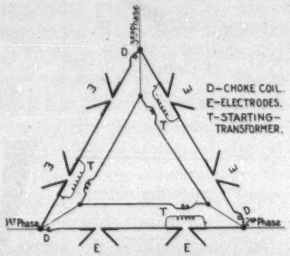
between the electrodes and projects above them, often attaining a height of three feet.

The wrought-iron, refractory-lined furnace (Fig. 8), which is rectangular in shape with a cross section of 3.8×4 feet and a height of 10 feet, contains two sets of electrodes arranged in series. Air enters beneath each set of electrodes through the inlets A, while the nitrous gases leave through the common out-

let B. A portion of the nitrous gases from the furnace is switched off and returned through the hollow dividing wall C, after being cooled down to the proper temperature. This gas enters the upper portion of the furnace where it rapidly cools the nitrous gases from the arcs without diluting them.

One furnace with two arcs in series is placed in each leg of a three-phase current supply. Since a much higher E. M. F. is required for kindling an arc than for its maintenance when once kindled, a transformer (T, Fig. 9) producing an ancillary current of high E. M. F., but of low power, is connected across one pair of electrodes of each series. The high tension coil of this transformer gives an E. M. F. which is several times greater than

FIG. 9.



PAULING ELECTRODES IN SERIES ON EACH PHASE.

that of the main supply, so that the current which is shunted through the primary induces a voltage sufficiently high to kindle the arc. By means of an ingenious switching device the ancillary current comes into play when high tension is required for kindling the arcs, but is shut off when the main circuit is completed through the sheets of electric flame which develop between the furnace electrodes. If an arc is accidentally extinguished, the secondary current is automatically switched on.

(*d*) *The Kilburn Scott Furnace.*

Before concluding the consideration of different types of arc furnaces, a brief description should be included of the Kilburn Scott furnace, as it has the advantages of simplicity, conservation of heat, low first and maintenance costs, and a relatively good yield of nitric oxide.

This furnace, which is shown diagramatically in Fig. 10, employs three wedge-shaped electrodes, E, spaced 120° apart, having their sides inclined towards each other 30° from the vertical, and arranged with intervening refractory material, R′, so as to form a six-sided conical space with the apex at the bottom. Each electrode is connected through inductance to one leg of a 2000 volt three-phase circuit.

FIG. 10.

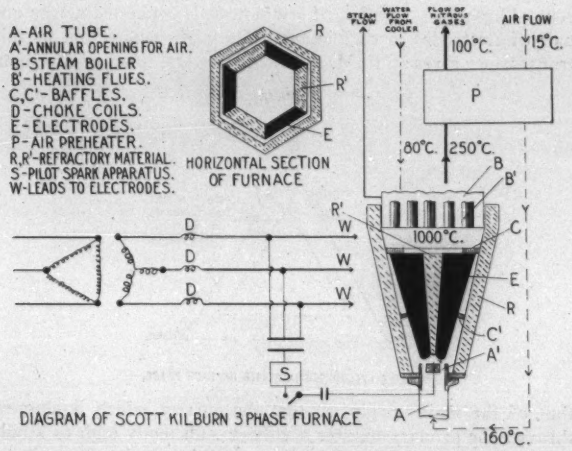


DIAGRAM OF SCOTT KILBURN 3 PHASE FURNACE

The air enters the bottom of the furnace directly beneath the electrodes through the annular opening A, and is prevented from escaping without passing through the arc by the baffles, C and C′. With a three-phase current of 60 periods, a combined arc consisting of 360 separate flames per second is flared out by the air current into what appears as a double cone having one apex at the bottom and the other at the top. High frequency "pilot" sparks from the apparatus S serve to break down the dielectric resistance and allow the main current to arc between the electrodes.

A tubular boiler, B, with heating flues, B′, placed directly above the arc and through which the nitrous gases from the furnace pass, cools these gases from about 1000° C. to 250° C. and utilizes the waste heat.

THE CONVERSION OF NITRIC OXIDE TO NITRIC ACID, ETC.

The following outline of the method of the conversion of the nitric oxide formed in the arc furnace into nitric acid, nitrates and nitrites is illustrated by the diagram shown in Fig. 11.

Air is forced by a powerful blower into a large iron pipe line which conveys it to the furnace, where it is partially oxidized to nitric oxide. The nitrous gases, which leave the furnace at a temperature of somewhat over 1000° C., are then carried by a refractory-lined iron main to a tubular steam boiler, in which the gases during their passage through the heating flues have their temperature reduced to 200° C.–250° C. The steam produced in this boiler is utilized for operating evaporating kettles, running the engines which compress the air to work the pumps, etc. By the use of a turbo-generator in conjunction with the steam boiler, 10–15 per cent. of the energy consumed in the furnace can be regenerated. The boiler may either form a part of the furnace, as in the Kilburn Scott process, or it may be separate, as in the Norwegian installations. It is important that the feed water of the boiler should be sufficiently hot to prevent moisture being deposited on the tubes, and this is readily accomplished by employing water from the cooling tank and also that which is used to cool the electrodes, thus giving a further saving of heat.

From the steam boiler the nitrous gases pass on to a cooling tank, where their temperature is further reduced to about 50° C. This tank consists of a large number of aluminum tubes over which cold water flows and through which the gases pass.

On leaving the cooler the gases are led to an oxidation tank. This is a large iron cylinder lined with acid-proof stone. Here the gases are allowed to remain in gentle motion for a short time, in order that the nitric oxide may be oxidized to nitrogen peroxide, the air which accompanies the gases from the furnace containing sufficient oxygen for this purpose. The extent of oxidation depends upon the length of time the gases are allowed to remain in the tank, 12 seconds being required for 50 per cent.

and 100 seconds for 90 per cent. oxidation of a furnace gas containing 2 per cent. of nitric oxide.

Blowers force the gases from the oxidation chamber through an aluminum pipe-line to the absorption towers. These towers are made of granite or iron and are filled with broken quartz, which is acted upon by neither the nitrous gases nor the nitric acid. At the Birkeland-Eyde plants, in Norway, these towers are 65.62 feet high and 18 feet in diameter. In these plants a series of three granite towers for the formation of acid followed by one of two iron towers for the formation of nitrite is usually employed. Centrifugal aluminum fans assist the passage of the gases through the towers.

FIG. 11.

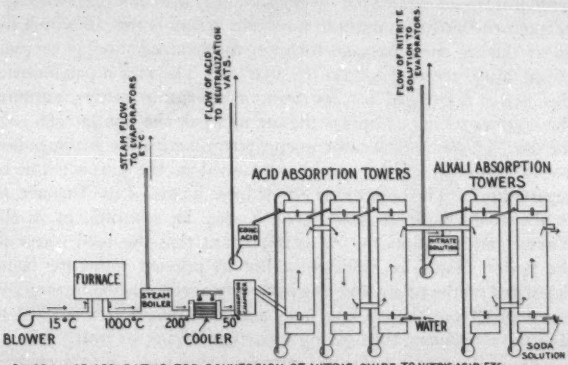


DIAGRAM OF APPARATUS FOR CONVERSION OF NITRIC OXIDE TO NITRIC ACID ETC.

The gases enter the first tower at the bottom, pass upwards, and thence are led by an earthen-ware pipe to the top of the second tower, down through which they pass and then through a second earthen-ware pipe are conducted to the bottom of the third tower. From the top of this tower they are conveyed to the first of the two iron towers. Water trickling down through the quartz in the third tower is gradually converted into dilute nitric acid which is received in a cistern at the bottom. The arrangement of the absorbing system is such that the liquid can be pumped up and passed repeatedly through the same tower, or

used to percolate the preceding tower and so be brought in contact with a higher nitrogen peroxide concentration. After the absorbing liquid is pumped to the reservoirs at the top of the towers, it is automatically distributed in jets by earthen-ware pipes. When the acid concentration of the percolating liquid has attained a concentration of about 33 per cent., it is pumped to naturalization vats and converted into calcium nitrate or ammonium nitrate, or the dilute acid is further concentrated in the usual way.

Since on leaving the third tower the gases still contain upwards of 20 per cent. of the original nitric oxide concentration, they are passed through the two iron towers percolated by a solution of caustic soda, in which absorption is more rapid and complete than in water. Of the entire quantity of nitrous gases passed through the five towers, about 97 per cent. is absorbed. By regulating the time the nitrous gases are allowed to remain in the oxidation tank, the proportions of nitric oxide and nitrogen peroxide in the gas which comes from the third tower can be made such that practically pure nitrite will be formed in the alkali towers. Sodium nitrite, free from nitrate, can also be produced by leading the nitrous gases directly to the second set of towers when their temperature has been reduced to 250° C., since at this temperature the two oxides of nitrogen are present in the gas mixture in equimolar proportions.

At Rjukan II, in Norway, the distance between the furnaces and the absorption towers is about 3000 feet.

POWER, CURRENT SUPPLIES, YIELDS, ETC.

Of the different electrical processes for the fixation of atmospheric nitrogen, only the arc process is capable of intermittent operation with off-peak power. Arc furnaces, therefore, may be installed wherever cheap three-phase power is available for sixteen to twenty hours per day. It is not even necessary to install special generating machinery, as the ordinary standard voltages of 5500 and 6600 and periodicities of 25 and 60 are suitable.

A factory of convenient size for the fixation of atmospheric nitrogen is one which has a capacity of about 10,000 kilowatts, but in larger factories the cost per kilowatt, the operation cost, and the overhead charges per unit of finished product, are relatively lower.

The current supplies required for the first three furnaces that have been described are as follows:

The Birkeland-Eyde Furnace.—Direct current for the magnetic field of 4500 lines of force per square centimetre.

Alternating current of 5000 volts and 50 periods for furnaces having a capacity of 600–4000 kilowatts.

The Schönherr Furnace.—Alternating current of 4200 volts and 50 periods for furnaces having a capacity of 600–1000 kilowatts.

The Pauling Furnace.—Single-phase alternating current of 4000–6000 volts and 50 periods for furnaces having a capacity of 400–1000 kilowatts.

The average yield of nitric acid in the Birkeland-Eyde furnace is between 500 and 600 kilogrammes per kilowatt year, although with some furnaces it has run as high as 950 kilogrammes. In the Schönherr and the Pauling furnaces it amounts to 675 kilogrammes and 525 kilogrammes, respectively, per kilowatt year.

The production of nitric acid and nitrates from atmospheric nitrogen by the arc processes has made rapid strides in Norway, increasing from about 1000 tons in 1905 to an annual output of upwards of 100,000 tons at the present time. The Norwegian installations are located at Notodden and other parts of the Telemark district in southern Norway, where abundant water power is available at a very low cost. By constructing a dam a short distance below Lake Mös, a reservoir was created with a storage capacity of 190 thousand million gallons, thereby ensuring a constant water supply for two of the largest power stations.

ADVANTAGES AND DISADVANTAGES OF THE ARC PROCESSES.

The advantages of the arc processes may be summarized as follows:

1. Cheapest cost of nitric acid (not of fixed nitrogen) if power can be obtained for $13 per kilowatt year or less, and efficiently utilized in a large plant run continuously to capacity.

2. Efficient intermittent operation is possible with off-peak power.

3. The steam required for the concentration of the nitric acid and other purposes may be produced from the large amount of waste heat.

4. Direct production of nitric acid without intermediate products.

5. Free raw materials.

6. Labor requirements are small.

The following are the chief disadvantages of the arc processes:

1. Large power requirements per ton of nitric acid.

2. Greater dilution of nitric acid when first produced than by other processes.

3. High installation charges for both power and plant.

4. Difficulties involved in the transportation of nitric acid.

II. THE DIRECT COMBINATION OF HYDROGEN WITH NITROGEN.

OUTLINE OF THE UNDERLYING PRINCIPLES.

It has long been known that under certain conditions small traces of ammonia can be formed in a mixture of hydrogen and nitrogen, but it is due to the brilliant pioneer work of Haber and the subsequent development of his methods by the Badische Anilin and Soda Fabrik, that the production of ammonia from its constituents on a successfully commercial scale has been achieved. However, notwithstanding the fact that over a million tons per annum of synthetic ammonium sulphate are produced by the company just referred to, but very meagre details regarding the process are available.

The reaction between hydrogen and nitrogen leads to an equilibrium according to the equation:

$$N_2+3H_2 \rightleftarrows 2NH_3. \tag{8}$$

This equilibrium is represented by the expression:

$$K=\frac{p_{NH_3}}{p_{N_2}^{\frac{1}{2}} \cdot p_{H_2}^{\frac{3}{2}}}, \tag{9}$$

where p represents the partial pressures of the respective gases at equilibrium and K is the equilibrium constant. If in (9) there is substituted for the partial pressure the product of the total pressure, P, and the fraction, C, which each gas forms of the total volume at equilibrium, the equation takes the form:

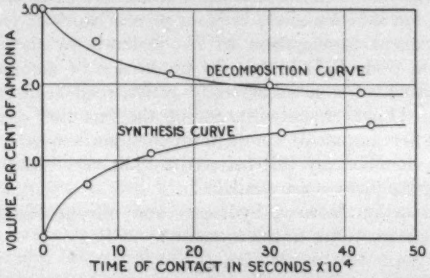
$$P.K=\frac{C_{NH_3}}{C_{N_2}^{\frac{1}{2}} \cdot C_{H_2}^{\frac{3}{2}}}. \tag{10}$$

The formation of ammonia from hydrogen and nitrogen is an exothermic reaction, and at ordinary temperatures it is accompanied by an evolution of 11,890 gramme-calories per mole of

ammonia. It follows, consequently, in accordance with Le Chatelier's law, that the concentration of ammonia present in the gas mixture at equilibrium must diminish as the temperature at which the reaction takes place is increased. In order, therefore, to obtain a high concentration of ammonia, the temperature must be kept as low as possible. Unfortunately, on the other hand, a high temperature is necessary to obtain a favorable velocity of reaction.

The thermal synthesis of ammonia has been studied recently by Maxted [3] by passing mixtures of hydrogen and nitrogen through a small arc contained in a capillary tube. His investigations showed, as is illustrated graphically in Fig. 12, that at a temperature of about 3000° C. the amount of ammonia present

FIG. 12.



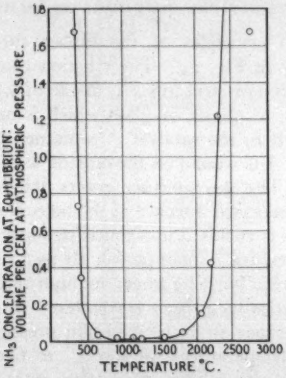
in the gas mixture after passing through the arc increased with the time the hydrogen-nitrogen mixture remained in contact with the arc. Since the "synthesis curve" indicated that, under the conditions employed, the ammonia concentration at equilibrium is between 1.5 and 2 per cent. by volume, hydrogen-nitrogen mixtures containing 3 per cent. of ammonia were passed through the arc. As is shown by the "decomposition curve" in Fig. 12, the ammonia concentration being above its equilibrium value sank instead of rising after contact with the arc. This second curve shows that the equilibrium concentration of ammonia is about 1.7 per cent. at atmospheric pressure under the conditions studied. Maxted has also plotted out approximately the complete experi-

[3] Maxted, E. B., *J. Soc. Chem. Ind.*, 37, 232 (1918).

mental ammonia curve up to a temperature of 3000 °C. This curve is shown in Fig. 13.

As it is evident from equation (10) that, for a given temperature, the ammonia concentration at equilibrium will be higher the greater the pressure at which the reaction is carried out, the best conditions for the formation of ammonia from its constituents are, therefore, a high pressure and a low temperature. But as the velocity with which equilibrium is attained under the latter condition is extremely slow, it is accelerated by employing a catalyst. By means of suitable catalysts, it is possible to attain equilibrium rapidly and to produce satisfactory concentrations of ammonia at pressures between 150 and 200 atmospheres at

FIG. 13.



500° C. to 600° C. But even with the most active catalysts at present known, it is difficult to obtain satisfactory results below the former temperature. On the other hand, it is unnecessary to operate at temperatures over 700° C., for with a gas mixture containing one volume of nitrogen to three volumes of hydrogen the maximum concentration of ammonia is rapidly attained below this temperature. With this gas mixture the equilibrium concentration of ammonia decreases with rise in temperature at a constant pressure, and for a given temperature increases with the pressure, as is illustrated by the data given in Table IV.

TABLE IV.

Temperature ° C.	Equilibrium concentration of ammonia at pressures of:		
	1 atmosphere.	100 atmospheres.	200 atmospheres.
400	0.48	.....	....
500	0.13	10.7	18.1
550	.....	7.0	12.2
600	0.048	4.5	8.3
650	.....	3.0	5.8
700	0.021	2.1	4.1
750	0.0159	1.54	2.99
800	0.011	1.1	....
850	0.0089	0.874	1.68
950	0.0055	0.542	1.07
1000	0.0032	.....	....

THE TECHNICAL SYNTHESIS OF AMMONIA.

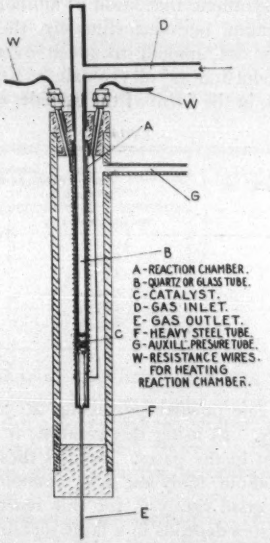
The essential principles of the Haber furnace are shown diagrammatically in Fig. 14. The reaction chamber consists of a thin wrought iron or steel tube, A, inside of which is contained a second tube, B, of quartz or glass which is narrowed towards the lower end where the catalyst is contained between asbestos plugs. The tube A is wound on the outside with a heating resistance wire, W. The gas mixture enters the reaction chamber through D and leaves the furnace at the bottom through E. The reaction chamber is enclosed in a much stronger steel tube, F, in which a high pressure is maintained, so as to prevent the hot, thin, steel tube from bursting under its high internal pressure.

Many difficulties have been encountered in the construction of the Haber furnace so as to maintain pressures of over 150 atmospheres at temperatures of 500° C. to 600° C. At about 400° C. iron loses its solidity to a very extraordinary degree. Steel loses its carbon at the temperatures employed, thus reducing to a minimum its capacity of withstanding pressure. Iron becomes pervious to hydrogen under the high pressures, and its properties change. Further, the wall of the reaction chamber rapidly deteriorates under the influence of the ammonia mixture at high temperatures. While these difficulties have been overcome, the details have been kept secret. Also there is but little information regarding the details of the construction of the furnace and its operation. It is known that the process is not without danger, as very small amounts of oxygen or air are sufficient

to cause explosion at high pressures, but this danger is guarded against by having the apparatus in bomb-proof chambers.

Since the electrical method of heating is attended with many difficulties, a system has been adopted in Germany in which a sufficient quantity of air is introduced into the catalyst chamber, in such a manner that the proper reaction temperature is maintained by internal combustion. While this method of heating simplifies the construction of the furnace, it is liable to give rise to explosions owing to the incomplete combustion of the air.

FIG. 14.



VERTICAL SECTION OF A HABER FURNACE

The hydrogen-nitrogen mixture is forced through the furnace at such a velocity that an ammonia concentration of about 8 per cent. is maintained. On leaving the furnace, the gases pass through a refrigerating system where the ammonia is liquefied, while the hydrogen and nitrogen are returned to the reaction chamber and are again passed over the catalyst. Since in the

reaction the first portions of ammonia are formed more rapidly than successive increments, it is desirable to remove the ammonia as completely as possible before returning the residual gases to the reaction chamber. The maximum temperature that can be employed in the refrigerating system depends upon both the ammonia concentration and the pressure of the gas mixture. In Table V is recorded the theoretical percentage of ammonia left in a gas under two different pressures after passing through a refrigerating system at the designated temperatures.

Of the various catalysts investigated for accelerating the velocity of the synthetic formation of ammonia, by far the most effective is osmium, but, unfortunately, the world's supply of this metal does not amount to much over 200 pounds, and the annual production is very small. Next in order comes uranium, which, in the form of the carbide, crumbles under high

TABLE V.

Temperature ° C.	Per cent. of ammonia remaining in the residual gas mixture when the pressure is:	
	150 atmospheres.	200 atmospheres.
0	2.7	2.1
−10	1.9	1.4
−20	1.2	0.9
−30	0.76	0.57
−40	0.47	0.35
−50	0.25	0.19
−60	0.13	0.1

pressures to a fine powder possessing at 500° C. a very high catalytic activity. In using this catalyst, it is essential that no water be present in the gases. Besides these two metals, iron, tungsten, molybdium, molybdic acid, ammonium molybdate and manganese are good catalysts for this reaction. The catalytic activity of tungsten depends in a large measure upon the manner in which it is prepared. It is worthy of note that platinum, although very closely related to osmium, possesses but a very slight catalytic activity.

Certain foreign substances—"promoters"—have been found to increase the activity of the catalyst. The most effective of these are the oxides and hydroxides of the alkali metals and of the metals of the alkali earths. For example, an iron-potash

catalyst is particularly active. In many cases just a minute quantity of the promoter is sufficient to increase the catalytic activity.

As is so often the case with catalysts, those employed in the synthesis of ammonia are very susceptible to poisoning. Thus, sulphur, selenium, tellurium, phosphorus, arsenic, boron or their hydrides, as well as lead, bismuth, tin, and many organic compounds behave as poisons. Extremely minute quantities of oxygen-sulphur compounds, which are almost always present in the so-called pure gases of commerce, suffice to render the catalyst either absolutely inactive or to diminish its activity very considerably. Iron prepared from its oxide containing 0.01 per cent. sodium sulphate or 0.1 per cent. sulphur is quite useless as a catalyst. Recognition of these facts necessitates the preparation of the catalyst free from such poisons, as well as very careful preparation of the gases employed in the reaction. Since as little

TABLE VI.

Time of contact with catalyst in seconds.	Percentage of ammonia formed.	Yield of ammonia in kilograms per hour per liter of catalyst space.
0.34	0.65	2.7
0.56	0.94	2.3
1.8	1.8	1.4
3.6	3.2	1.25
7.2	4.7	0.91
10.8	5.1	0.65
24.5	6.8	0.38

as one part of sulphur in a million in the gas mixture can be injurious, even electrolytic hydrogen must be further purified.

The time of contact between the gas mixture and the catalyst influences the amount of ammonia formed. This is illustrated by Table VI, which gives both the percentage and yield of ammonia produced at 550° C. and a pressure of 150 atmospheres in the presence of an iron-potash catalyst.

The data in Table VI show that for a catalyst chamber of given size the highest yield of ammonia is obtained when the time of contact and the percentage of ammonia formed are both small. However, since any decrease in the percentage of ammonia formed involves an increase in the number of circulations of the gas mixture through the reaction chamber and the delivery of a greater quantity of heat to the refrigerating system, the most

economical condition for the synthesis is not a maximum yield of ammonia per hour, but an optimum rate of circulation of the gases.

The variation in the percentage and yield of ammonia with temperature and pressure, employing an iron-potash catalyst and time of contact of 1.8 seconds, is illustrated in Table VII.

It has been found that the best results are obtained when the pressure in the reaction chamber is maintained at 180 atmospheres. Regarding the most suitable working temperature, Maxted [4] points out "it must be borne in mind that, as the synthesis is usually carried out, the percentage of ammonia formed per passage never approaches the equilibrium value for the temperature and pressure used, and thus, within limits, of course, reaction velocity will play an even more important rôle in the

TABLE VII.

Pressure = 150 atmospheres.			Temperature = 550° C.		
Temperature ° C.	Per cent. NH_3	Yield in kg. per hour per liter of catalyst space.	Pressure atmosphere.	Per cent. NH_3	Yield in kg. per hour per liter of catalyst space.
530	1.85	1.55	50	0.55	0.42
			150	1.8	1.4
580	3.57	2.73	180	3.5	2.7

determination of the amount of ammonia formed during the time of contact than the absolute value of the equilibrium ammonia percentage. If, on the other hand, the temperature employed be so high that the desired percentage of ammonia unduly approaches the equilibrium percentage, the increase in the reaction velocity due to increased temperature will no longer compensate for the decreased equilibrium ammonia content."

On account of the small and complicated units employed in the Haber process, a large amount of highly skilled labor is required. Further, the technical control of the process is of so great importance and requires such skill that many months are necessary to train a technical staff of experts.

A process which resembles the Haber process has recently been invented in this country by DeJahn of the General Chemical Company, but very little is known regarding its details. One

[4] Maxted, E. B., *loc. cit.*

great advantage of this process over that developed by Haber is that the reaction is carried out at a much lower pressure. Ammonia is formed by passing a mixture of hydrogen and nitrogen at 520° C. to 540° C., under a pressure of 80 to 90 atmospheres, over a catalyst formed by igniting a salt of cobalt, manganese, titanium, cerium, boron, uranium or silicon upon a carrier of pumice, and then heating the product (after reduction in hydrogen) with metallic sodium and anhydrous ammonia at 300° C. Satisfactory results have also been obtained with a catalyst made by reducing nickel oxide on pumice with hydrogen at 550° C., adding a small amount of metallic sodium, and heating in anhydrous ammonia to 450° C. With this catalyst 4.5 per cent. by volume of ammonia is obtained under a pressure of 80 to 90 atmospheres at a temperature of 520° C. to 540° C.

PREPARATION OF HYDROGEN AND NITROGEN.

The preparation and purification of the hydrogen and nitrogen involve one of the chief items of cost in the synthesis of ammonia.

The principal method employed for the preparation of pure nitrogen is the low temperature separation from air. It may also be obtained as a by-product in the manufacture of formic acid from producer gas and sodium hydroxide.

Although a pure hydrogen may be prepared electrolytically, its cost is very high. It may be produced much more cheaply by the alternate action of steam and water gas on iron. However, hydrogen prepared by this method contains 1 to 2 per cent. of carbon monoxide, its presence resulting as follows: During the reducing stage of the process, carbon monoxide decomposes according to the equation,

$$(11)\quad 2CO \rightleftarrows CO_2 + C,$$

the carbon being deposited on the iron and reacting with the steam subsequently introduced, with the re-formation of carbon monoxide which contaminates the hydrogen. By a modification of the intermittent method, whereby instead of water gas, a gas containing a sufficient concentration of carbon dioxide to prevent the separation of carbon, according to equation (11), is employed for reduction, hydrogen completely free from carbon monoxide and having as high a purity as the electrolytic gas, can be produced with practically no increase in cost. In addition to the

methods mentioned, hydrogen may also be obtained as a by-product in the electrolytic manufacture of alkali and in the manufacture of oxalates from formates.

Since the presence of even small traces of impurities in the hydrogen and nitrogen may poison the catalyst, their removal is essential. The methods employed depend on the nature of the impurities, and consist, according to the case, in filtering, washing, conducting over solid absorption agents, and so on. One good method is to bring the gases at high temperature into contact with the material of which the catalyst is prepared, before passing them over the catalyst. This material takes up the impurities, and from time to time is renewed.

PRODUCTION AND COSTS.

The Haber process for the production of synthetic ammonia was installed in Germany in 1913 with a plant capacity of 30,000 tons of ammonium sulphate per annum. This grew to 60,000 tons in 1914; 150,000 tons in 1915; 300,000 tons in 1916; and 500,000 tons in 1917. At the present time ammonia is produced synthetically also in this country and in England. In 1918 the world's production of synthetic ammonia amounted to 140,000 tons.

Ammonia can be produced more cheaply by the synthetic method than by any other. In the Haber process the total energy consumption is given as 1.5 kilowatt hours per kilogramme of nitrogen fixed. Trustworthy information indicates that anhydrous ammonia can be produced in the liquid condition by the Haber process for slightly less than four cents per pound.

ADVANTAGES AND DISADVANTAGES.

The chief advantages of the Haber process for the production of synthetic ammonia are:

1. Cheap ammonia.
2. Anhydrous ammonia in the liquid condition ready for immediate oxidation to nitric acid without purification.
3. Cheap and available raw materials.
4. Possibility of erecting comparatively small plants whenever required.

The following constitute the principal disadvantages:

1. Difficulties involved in the construction of apparatus to withstand high temperatures and high pressures.
2. The highly skilled technical staff required.
3. High repair and renewal costs.

(To be concluded.)

THE VISIBILITY OF AIRPLANES.*†

BY

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On clear days areas of water are somewhat less conspicuous amid the landscape viewed obliquely than on cloudy and overcast days. That is, the areas on clear days as viewed obliquely are of lower relative brightness than on cloudy and overcast days. This is very noticeable to the eye and is somewhat indicated in Table I. Some small lakes and ponds are strikingly dark amid their surroundings, sometimes appearing almost black. If a pool is clear and deep, with a porous bottom of low reflection-factor, practically the entire brightness is that due to specular reflection from the surface. It has been noted that this is only about 0.02 for a smooth surface of water viewed perpendicularly. Considering this in connection with the data in Tables I and II, it is seen that such a pool would appear very dark.

Values of the brightness of water in terms of that of the zenith sky, both being viewed perpendicularly and simultaneously, as obtained on various days, are presented in the following table:

TABLE II.

Relative Brightness of Inland Water Viewed Perpendicularly in Terms of Brightness of Zenith Blue Sky.

4:30 P.M.	Sunny day, large clouds	0.58
10:30 A.M.	Clear day	.63
10:00 A.M.	Clear day, some clouds	.80
9:30 A.M.	Clear day, some clouds	.87
2:00 P.M.	Clear day	.99
1:30 P.M.	Clear day, some clouds, high altitude	1.40
1:30 P.M.	Clear day, deep blue sky	.79
	Mean	.87

Some values of the brightness of areas of water viewed at 45 degrees in terms of the brightness of the zenith sky varied from 1.5 to 3.0. The mean of a few values obtained is about 2.2. The brightness was usually much greater at very oblique angles.

* Based on a paper presented at a meeting of the Section of Physics and Chemistry held Thursday, January 9, 1919.

† Concluded from page 312, Vol. 187, March, 1919.

These values varied considerably at any given time, depending upon the direction of the observation with respect to the sun. The values obtained by viewing a given surface vertically were quite constant over a wide range of sky and weather conditions.

The foregoing measurements of the apparent reflection-factor or the relative brightness of water were made entirely over inland waters such as rivers and the Chesapeake Bay. Such measurements are perhaps generally satisfactory for the purpose in mind; however, inasmuch as such data form the foundation for attaining low visibility for seaplanes similar measurements were made over deep water more than 50 miles from land. A series of measurements were made during an eight-hour flight over Hampton Roads, the Chesapeake Bay, through the Virginia Capes and 50 miles to sea from altitudes varying from 400 to 1200 feet. As in the previous work all measurements were made approximately at normal incidence with the surface of the water. The apparent reflector-factors follow:

Shallow water in Hampton Roads	7.4 per cent.
Deep channel in Chesapeake Bay	4.9 per cent.
Atlantic Ocean 10 to 50 miles from land	3.5 per cent.

The foregoing represent means of many observations. The lowest value obtained for deep water far from land was about 2 per cent., the highest was 5.6 per cent., the most of the values were confined to a range from 3 per cent. to 5 per cent. Of course, the brightness increased for oblique angles and varied with the position of the sun. However, if seaplanes were camouflaged with a dull coat according to the observations made vertically, they would automatically fit into the background fairly well for oblique viewing by appearing brighter at such angles because they cannot be provided with a perfectly matte surface, for the latter cannot be realized in practice. The net result of these observations at sea is to encourage a very dark color for seaplanes. However, it is likely that in many cases we would be concerned with more shallow and more turbid waters nearer shore. In regard to pattern, it does not appear desirable to use more than a slight one if any. This is a matter which may be settled with ease after beginning with the more important data which is available concerning reflection-factor and hue. The difference in hue between shallow turbid water and deep clear water is apparent. The former

is a dirty greenish hue for the inland waters studied and the latter is a purer greenish blue.

When these measurements were made far out over the ocean the sky was clear for a portion of the time and then became covered with filmy clouds or a cloud haze; however, the sun was clearly visible. The brightness of the deep water was only 0.3 that of the hazy sky, but the values varied from 0.16 to 1.0. Of course these depend not only upon the depth and clearness of the water but also upon the brightness of the sky, which varies considerably.

From such evidence and other considerations in this report it should be a simple and clear-cut procedure to render seaplanes of the lowest visibility for average conditions as viewed from above. This aspect is discussed in Section 18.

In Fig. 8 it is seen that the water appears of a brightness approximately midway between the brightness of barren land and the brightness of the wooded areas and about equal to that of fields of growing crops. Owing to the fact that the clouds cast very perceptible shadows on the water (Fig. 10) it is evident that most of the brightness of water viewed vertically is due to sunlight diffused throughout it. The brightness of the stream of water in Fig. 8 is seen to be about a mean of the range of brightnesses in the photograph, which coincides with the data in Table I.

TABLE III.

Relative Brightness of Various Types of Areas
(Zenith sky=B).

Woods.	Water.	Fields.	Ploughed or Barren Land.
0.44*B*	0.53*B*	1.02*B*	—
.36	—	.67	—
.45	.58	.86	—
.50	.73	—	—
.40	.80	.77	1.08
.53	.91	.93	1.19
	.72	.62	—
Mean 0.45*B*	0.71*B**	0.81*B*	1.14*B*

Landscape covered with hazy clouds	3.5 *B*
Upper sunlit sides of cumulus clouds	5 to 10 *B*
Under side of massive cumulus clouds	1.4*B*

*Not the same set as in Table II.

10. THE SKY.

Although the most helpful data upon which to base the practical efforts of realizing low visibility for airplanes are those pertaining to the apparent reflection-factors of the various areas in landscapes, data pertaining to the sky is of considerable importance. The former data have been presented also under the designation of "relative brightness." This is a better term but is liable to be confusing. Unless otherwise stated, it always means in this report the brightness of an area relative to the brightness of a perfectly reflecting and diffusing white surface under the same illumination.

Some of the data pertaining to the sky were obtained as indirect checks upon other values but much of the data need not be presented or discussed. It was shown in Fig. 4 that the clear sky varies in brightness throughout a day and usually varies greatly from zenith to horizon. The brightness of the sky in absolute units varies generally between 0.5 and 2.0 lamberts, one lambert being a fair average brightness as measured from the earth's surface.

It is of interest to know the brightnesses of various areas in terms of the sky-brightness B, but these values should not be confused with those values of "relative brightness" which are in reality "apparent reflection-factors." The mean values obtained for various areas are presented in Table III in terms of the zenith sky-brightnesses B.

The values for clouds and for water are discussed in preceding sections (7 and 9) under their respective headings. The upper surfaces of the upper wings of airplanes finished a yellowish-white were several times brighter than the zenith sky. At the critical angles for specular reflection of direct sunlight the values were enormously greater. The brightness of the upper wings as viewed from beneath were about 0.05, the brightness of a perfectly reflecting and diffusing white surface receiving the same illumination that the upper surface of the wings received. As viewed from below these wings in their most translucent portions were only about 0.25 the brightness of the sky on a clear day. On an overcast day they would be only about 0.05 the brightness of the sky. Much of the framework of an airplane is opaque, so it is seen that an airplane as a whole appears very dark when viewed against the sky. These points are discussed further in a later section.

It is interesting to note that the data in Table III were obtained independently from those in Table I, with an instrument of a different type, and on different days. However, when reduced to the same value for water they compare thus:

	Fields.	Barren Land.	Woods.	Water.
Table I	6.8	13.0	4.3	6.8
Table II	7.7	10.9	4.3	6.8

This is an excellent check when all aspects of the problem are considered. Incidentally many checks on the absolute values were made with different instruments.

A number of determinations of the portion of the total light contributed by the sky on clear days were made at the earth's surface. These averaged about 0.16. In other words, the sky contributed about one-sixth and the sun about five-sixths of the total light on the earth's surface during the clear days of this period and in this locality. Let us assume the mean sky brightness equal to B and the brightness of a perfectly reflecting and diffusing horizontal surface due to sunlight equal to 5 B. By weighting the values of earth brightness in terms of the mean sky brightness (which is greater than the brightness of the zenith sky) let us assume that the mean brightness of the earth equal to 0.4 B. Then

$$RB\,(5+1) = 0.4B$$

$$R = \frac{0.4}{6} = 0.066$$

where R is the mean apparent reflection-factor of the earth. This is approximately the weighted mean arrived at by measurement. Inasmuch as the assumption cannot be far from correct this serves as a check for the data in Table I.

When viewing the earth from high altitudes, the haze which is a luminous veil owing to the light reflected by the suspended particles, may add some brightness to that of the earth. No very accurate measurements of the luminosity of this veil were obtained, but it does not appear to add very much to the mean brightness of the earth when the latter was viewed vertically from a high altitude. As we ascend, the blue sky becomes less bright and more saturated in color. For this reason the brightness of the earth in terms of that of the sky increases with the altitude of observation. Some measurements at altitudes of 10,000 to

20,000 feet on a clear day yielded the following brightnesses in terms of the zenith sky brightness B:

Fields	1.1 B
Water	1.4 B
Landscape covered with thin clouds	3.5 B
Dense sunlit clouds	11.0 B

At very high altitudes the sky was very dark blue and measurements indicated that it was contributing only about 5 per cent. of the total light at midday at an altitude of 18,000 feet. There are reasons for expecting even lower values than 5 per cent. at the highest attainable altitudes. A mean of a number of measurements at 18,000 feet indicated that the lower horizontal surface of a perfectly reflecting and diffusing opaque object (reflection-factor = 1) would be 1.7 times the brightness of that particular zenith sky as observed at that altitude. In accordance with the preceding computation, assuming that the sky was of uniform brightness and contributed 0.05 of the total light,

$$RB\,(19+1) = 1.7\,B$$

Therefore R, the mean apparent reflection-factor of the earth would be equal 0.085. Considering that the earth haze may be responsible for some increase in the light which reaches the lower horizontal surface of the theoretical perfectly reflecting and diffusing object the value 0.085 appears to check well with preceding values.

Inasmuch as the brightness of the lower surfaces of airplanes is of interest from the standpoint of visibility as viewed from below against the sky, this aspect will be further considered. The amount of light reflected upward from the earth and the haze was measured on different days. From these observations the brightness of the lower horizontal surface of a perfectly reflecting and diffusing object was determined in terms of the brightness B of the zenith sky.

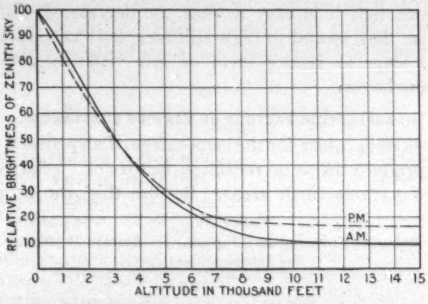
A mean of observations of this value made at altitudes from 7000 to 13,000 feet with a few clouds at 5000 feet was found to be 0.9 B.

A mean of observations of this value made on another day at an altitude of 7000 feet with some clouds at 5000 feet (2000 feet below) was found to be 1.6 B.

A mean of observations of this value at altitudes from 10,000 to 18,000 feet on a fairly clear day was found to be 1.7 B.

In these cases there were no clouds directly below. Unfortunately the number of observations available are insufficient to indicate more than the order of magnitude of this value. The differences in the values presented above are due doubtless to different brightnesses of the sky, to clouds and to various other lighting conditions. From the mean of the three mean values and assuming an average apparent reflection-factor of the earth equal to 0.085 (including the possible contribution of the haze), we compute that the upper horizontal surface of a perfectly white opaque diffusing object would appear about 12 times brighter than the lower surface of such an object above the clouds and haze on a day representing a mean of these three days.

FIG. 12.



Variation of brightness of zenith sky with altitude of measurements, on a very hazy but cloudless day.

From the data in Table I, assuming a mean apparent reflection-factor of the earth equal to 0.07, the upper surface would be about 14 times brighter than the lower surface when the opaque object is a few thousand feet above the earth. Under these conditions, the brightness of the lower side of the opaque object would equal the brightness of the sky (assuming it to be uniformly bright) on a clear day if the sky contributed one-fourteenth of the total light. This latter condition is never obtained at low altitudes.

Certain measurements were made pertaining to the haze. On a perfectly cloudless but hazy day the relative brightnesses of the zenith sky were measured at various altitudes from the earth's surface to 15,000 feet. In Fig. 12 the results are shown for the same day for morning and afternoon. The point where the curve

flattens out indicates the altitudes where the earth haze ends. These points are seen to be at about 10,000 feet and 7000 feet for morning and afternoon respectively on this particular day. These altitudes were roughly checked by others who were asked to estimate the extreme height of the earth haze. It is seen that the brightness of the sky decreases enormously with the altitude. This is of interest in the consideration of the visibility of airplanes as viewed from below.

From the viewpoint of visibility of airplanes as viewed from below, the haze and clouds not only form a veil which tends to obscure the aircraft but also emit light upward, tending to decrease the brightness contrast between the sky and the airplanes. Furthermore, the sky background is of lower brightness at high altitudes. Although it is easy to note the decreasing visibility of airplanes as they ascend to high altitudes, it is necessary to take additional steps to render them of low visibility generally as viewed from below.

II. REFLECTION-FACTORS OF VARIOUS SUBSTANCES.

In developing colors for the camouflage of airplanes it is necessary to reproduce the same reflection-factors or "relative brightnesses" of various earth areas. Besides this, the proper hues

TABLE IV.

Reflection-Factors of Dry Pigments for Average Daylight.

(See References 2 and 4.)

Pigment.	Reflection-Factor.
American vermilion	0.13
Venetian red	.11
Tuscan red	.11
Indian red	.10
Burnt sienna	.11
Raw sienna	.33
Golden ochre	.58
Chrome yellow ochre	.33
Yellow ochre	.49
Chrome yellow (medium)	.55
Chrome yellow (light)	.77
Chrome green (light)	.19
Chrome green (medium)	.14
Cobalt blue	.16
Ultramarine blue	.08
White pigments	.70–.90
Black pigments	.02–.04

After these pigments have been mixed with vehicles, the resulting paints will possess lower reflection-factors generally than the dry pigments.

must be obtained. These measurements can be made readily with proper apparatus, but it appears desirable to include data on reflection- and transmission-factors of dry pigments and of various other substances. The reflection and transmission characteristics of various types of media will be found in Reference 2.

12. GENERAL OBSERVATIONS.

A general qualitative study of the background and of the size of airplanes at various distances below the observer and above the earth was not only conducted while making photometric measurements but special flights were arranged for obtaining general notes. During this period of the investigation the writer had an opportunity to study a number of experiments on airplane camouflage as viewed from above, which were based merely on the judgment of an artist. Such experimental airplanes served the purpose for general observation which aided in convincing the

TABLE V.

Reflection-Factors of Various Substances.

(See Reference 2.)

	Reflection-Factor.
White blotting paper (dry)	0.70–0.85
White blotting paper (wet)	about 0.55
Tracing cloth	.30– .40
Tracing paper	.20– .30
Newspaper	.50– .70
White writing paper	.70– .75
Yellow copy paper	.65– .70
Parchment	.22
Same (2 thicknesses)	.35
Tissue paper (white)	.40
Same (2 thicknesses)	.55
Black cloth	.02
Black velvet	.004
Sulphur	.80
Cork	.25
Chocolate	.05
Paris green	.40
Manila paper	.50
White plaster	.70– .90
Copper (dull)	.25
Brass (dull)	.25– .35
Gold (dull)	.20
Silver mirror	.70– .90
Polished glass surface	.04
Aluminum (dull)	.60

writer of the necessity for the determination of many factors by extensive scientific measurements. Many of the results have been discussed in preceding sections.

From these and previous observations and considerations it appears that the following are the chief factors to be considered in striving for low visibility of airplanes as viewed from above:

1. Brightness.
2. Hue.
3. Size of pattern.
4 Shape of pattern.

Of these, the first is of greatest importance. From the standpoint of low visibility from below, where the sky is the background, obviously brightness and hue are the two chief factors to be considered.

Camouflage for low visibility as viewed from above will be different in late fall and in winter than in the spring, summer and early fall. As previously stated the important season is that of summer and the portions of the seasons close to it. Although other seasons will be touched upon the following conclusions pertain to the more important season, summer, and its vicinity.

All colors should be very dark shades; that is, mixed with black.

White should never be used.

Any coating which reduces the average reflection-factor below that of the natural yellowish-white of airplanes lowers the visibility generally.

Surfaces should be as dull as possible to avoid glint or highlights.

Apparently on a sunny day more conspicuous patterns and colors may be used owing to the greater contrasts of light and shade and the more generally enlivened landscape than on an overcast day.

All areas including sides and bottom of the fuselage and the surfaces of the wings should have the same general character of camouflage.

The upper side of the lower wing should possess a slightly greater reflection-factor in its central portion than the upper side of the upper wing in order to compensate for the lower illumination on the former area. This should apply somewhat to the lower surfaces of the wings but it must not be carried too far.

Haze is a factor which usually tends to lower the visibility of aircraft. This contributes materially when the observer is at

high altitudes or at long distances from the camouflaged craft which is in the haze that is at a low altitude.

Wooded areas are the darkest large areas of the landscape, except, of course, shadows of clouds on a sunny day.

Roads and barren ground are generally the brightest portions of landscapes.

Plain or solid colors for airplanes do not appear as satisfactory as broken or mottled pattern but contrasts in brightness should not be great.

Water when viewed vertically or at angles greater than 45 degrees generally appears of a brightness within the range of brightnesses of various earth areas.

Cultivated fields of growing crops are generally of a brightness closely approximating the mean of the landscape.

13. HUE.

No accurate measurements on the hues of the various earth areas were made, for it did not appear necessary. Nature's colors are generally deep shades, and inasmuch as the mean "relative brightness" (apparent reflection-factors) of the various earth areas were found to be very low, from 4 to 13 per cent., the hues to be used in airplane camouflage as viewed from above must be nearly submerged with black. Besides it is easy to approximate the hues closely by direct comparison of the paints with Nature's colors.

During the summer season, which we are chiefly considering, it is obvious that the yellowish greens of foliage, grass and trees, are overwhelmingly predominant. The dark buffs and other gray yellows and gray browns are seen in barren land and in sunburnt foliage. These two general hues are the most prominent. The shadows are a deep bluish shade on colorless areas and, therefore, are in general a blue-green shade of much lower brightness than the highlights. Inasmuch as the mean apparent reflection-factor of the earth's surface is of such a low value, any colors used for the purpose of lowering the visibility must be mixed with considerable black. This tends to reduce the importance of hue so that it appeared, together with other reasons, unnecessary to measure the hues accurately but to trust to qualitative studies, experience, and direct comparison for reproducing them with sufficient fidelity.

The color of inland water is a muddy greenish tint but partakes slightly of the color of the bottom where shallow.

The approximate mean hue may be arrived at in the following manner for any given landscape: A cardboard disk is laid out in sectors of various angles corresponding to the relative proportions of various types of areas on the earth's surface as estimated from observations and photographs. (These proportions can be accurately determined for any area by time records during flights.) Each sector is painted with the approximate color of the area which it represents, the reflection-factor being such as to closely correspond to that given in Table I. When this disk is rotated rapidly the mean reflection-factor will equal that of a landscape having the same proportions of the different areas. If the mean reflection-factor of a landscape is known, the mean of the disk must be made to equal it without altering the reflection-factors of the individual sectors. Therefore, the angles of the latter must be altered according to requirements.

These expedients do not give the exact hue, necessarily, but the general procedure appears to be satisfactory inasmuch as hue is of secondary importance.

Obviously the mean earth hue in late fall would be a more yellowish or brownish shade than in summer, and in winter it would be a tertiary gray and of a very high relative brightness in snow countries. The reflection-factor of fresh deep snow is about 0.8. The hues of the typical earth areas are not reproduced in color in this paper but the reflection-factors of the various patches as given in Table I and elsewhere, and the descrpition of the hues make it possible to visualize the actual colors. For experimental purposes these colors were mixed fresh from tubes and thinned slightly with turpentine. Inasmuch as the colors of large areas in a summer landscape are unsaturated shades—that is, shades of tints—grays of approximate luminosities or reflection-factors were first made. These were then tinted with color of the dominant hue desired. A given mixture was smoothed with a palette knife and the diffuse reflection-factor was determined photometrically, care being taken to avoid the critical angle of specular reflection. The mixture was altered until the correct reflection-factor and approximately correct hue were obtained in each case. If camouflage were to be adopted on a large scale it will be an

easy matter to standardize these samples in proportions by weight of commercial pigments or other coloring media and vehicles. Of course it is difficult to determine the reflection-factors of colored surfaces with high accuracy, but it is easy to attain the accuracy necessary in this work.

The components of the various colors for earth areas are as follows:

Fields.—Black, white, ultramarine blue and chrome yellow. Chrome green could be used instead of ultramarine blue and chrome yellow but the latter combination was used for supplying the green in order to roughly simulate the green of vegetation spectrally. Such a paint was developed shortly after our entrance into the war because it has a decided red component roughly approximating that in the spectrum of chlorophyll. If the airplane were to be viewed through special filters it would be less readily discovered if the spectrum of its coloring more closely approaches that of chlorophyll than would be obtained with chrome green or a combination of Prussian blue and chrome yellow. Owing to the extremely dark shades of green, which the measurements recorded in Table I and elsewhere demand, the foregoing refinement does not appear very essential.

Barren Land.—Obviously the blue will vary considerably with the character of the soil. This color consists of black, white, chrome yellow, and burnt sienna.

Water.—The hue will be somewhat different for shallow and deep water and will vary somewhat for different waters. Usually the variation will be toward green and yellowish green; that is, the bluish tinge will disappear, as the water becomes shallow.

Woods.—The combination is a darker shade of the color for fields of growing crops with a slight addition of blue.

Although the mean colors of various earth areas differ considerably, low visibility for airplanes viewed from above is certainly attainable. Of course, if we could develop a chamelon-like coating which would perform automatically and properly the ideal will have been obtained. Certain iridescent effects might be developed which would be satisfactory if such were necessary. However, it appears that the recommendations in this paper, if applied in practice, will render airplanes of exceedingly low visibility generally.

FIG. 13.

Landscape from 1000 feet.

FIG. 14.

Landscape from 2000 feet.

14. PATTERN.

The size of the pattern (if any) to be used in camouflage aimed to render airplanes of low visability as viewed from above, is of more importance than the actual shape. An airplane of 50-foot spread is a very small object when viewed at a few thousand feet; however, some slight pattern or mottling appears to be desirable. This feature was studied first by viewing various airplanes in flight, with different patterns and colors upon them, from positions varying from a few hundred feet to ten thousand feet above them. At the latter distance the airplanes were such tiny objects that pattern was of little importance. In fact, the importance of pattern decreased rapidly as the distance of observation increased beyond 5000 feet.

In order to study pattern carefully a series of photographs (4 in. × 5 in.) was taken of the same general landscape at altitudes of 1000, 2000, 3000, 5000, and 10,000 feet. These are shown respectively in Figs. 13, 14, 15, 16 and 17, and it will be noted that the characteristic areas of landscapes are present in most of them. In Fig. 18 the curve indicates the size of the image of a 50-foot object at various distances for the same photographic reduction as exists in the preceding series of photographs (Figs. 13 to 17). The focal length of the lens of the camera was 8.5 inches, therefore, if

h = altitude in feet, and
x = length in inches, of a 50-foot object

$$\frac{x}{8.5} = \frac{50}{h}$$

$$xh = 425$$

From this formula the sizes of images of a 50-foot object on the 4 in. × 5 in. photographs for different distances are as follows:

Distance.	Size of image.
1000 feet	0.425 inch.
2000 feet	.213 inch.
3000 feet	.142 inch.
5000 feet	.085 inch.
10000 feet	.043 inch.

For simplicity assume the spread of an airplane wing to be 50 feet and its width to be 5 feet. Then small rectangles, with lengths in inches given above and with corresponding widths one-tenth the length, can be superposed upon the photographs. Thus the size

FIG. 15.

Landscape from 3000 feet.

FIG. 16. Landscape from 5000 feet.

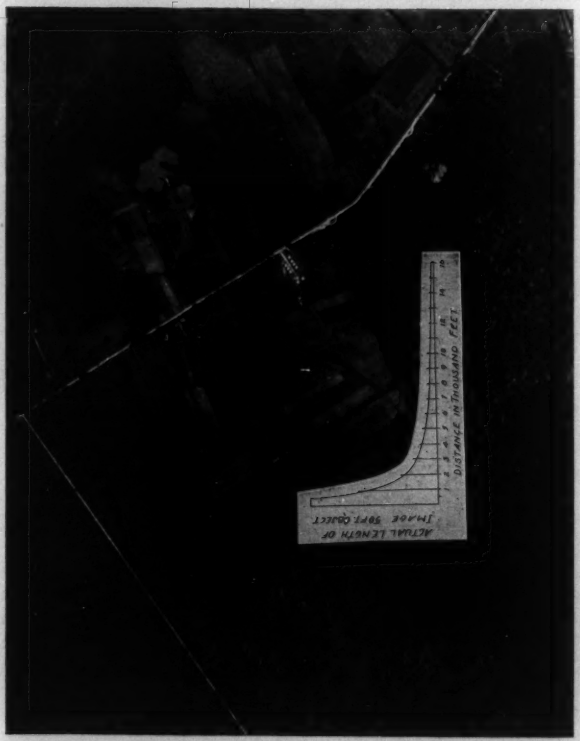
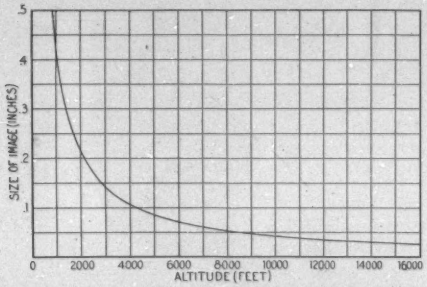


FIG. 17.

Landscape from 10,000 feet. The superposed curve shows the size of the image of a 50-foot object at various altitudes relative to the size of background patterns.

of an airplane at any altitude can be superposed upon this series of pictures in its truly relative dimensions. A curve showing the actual length of the image of a 50-foot airplane at different distances is superposed on Fig. 17. That is by this means an image of an airplane can be placed at any altitude between the earth and the observer and pattern can be studied in a positive manner. Unfortunately in this paper the illustrations are quite small for superposing these various rectangles for the purpose of studying size and shape of pattern for airplane camouflage, although much information can be gained from them. In the original work the photographs were sufficiently enlarged so that this method was satisfactory for studying pattern. However,

FIG. 18.



Showing relation between size of image of 50-foot object and altitude or distance. These values are correct for 4 inch by 5 inch reproductions of Figs. 13–17.

combining such experiments with experience at various altitudes in studying airplanes below, it is perhaps safe to confine the attention entirely to pattern requirements for airplanes within the range of 1000 to 5000 feet below the observer. From these photographs it is seen that it is futile to adopt a pattern (with many individual areas) which aims to simulate the irregular checkerboard appearance of cultivated fields. At any appreciable distance from the observer an airplane, regardless of its height, would generally be seen against a background consisting of a single field or at most two or three fields. This, if done accurately would be equivalent to painting the airplane almost a solid color or at most with only two or three areas of different contours and very slight contrast.

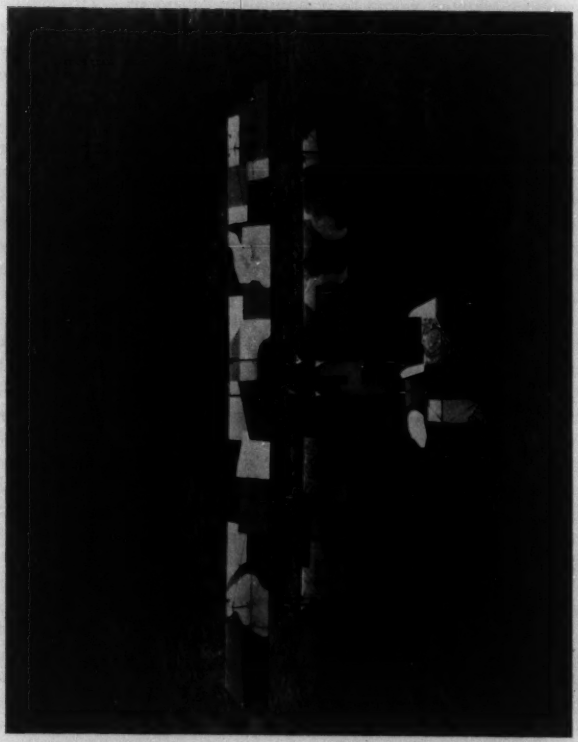


FIG. 19.

Illustrating some of the things which should not be done. Patterns very much too small; contrasts very great; colors not dark enough; light colors and white should never be used for camouflage to be viewed from above.

Although pattern is not of chief importance, it appears essential to use it to some degree in this type of camouflage. After studies of these photographs and many visual observations from various altitudes it appears that one of the best patterns which could be adopted would be a simulation of woods. This would provide pattern of a mottled sort (a very dark green with nearly black shadows), and inasmuch as clumps of trees are commonly found isolated in a landscape such a pattern would be appropriate over any area. The mean reflection-factor of this pattern might be a compromise of the apparent reflection-factor of various typical areas, but if such a pattern is adopted it appears best to have it appear not more than slightly brighter than dense woods so that it would be of low visibility over wooded areas. In fact, if it were of the same brightness and pattern as woods, the airplane would be practically invisible over wooded areas and apparently no more conspicuous over other areas than it would be if its brightness were a mean of the landscape brightnesses.

On the basis of the preceding photographs and of the information yielded by a study of Figs. 13 to 17, with the sizes of the images of the 50-foot airplane properly superposed, it is evident that the pattern of Fig. 19 consists of areas entirely too small. Furthermore, the areas of high brightness approaching white cause the airplane to be distinguished readily as it is moving over the more uniform areas such as fields and woods. Many other patterns were shown to be futile attempts at attaining low visibility of airplanes as viewed from above. Invariably attempts at camouflage for airplanes viewed from above were faulty in pattern and the colors used were not dark enough.

15. VISIBILITY OF AIRPLANES AS VIEWED FROM ABOVE.

Much of the material in previous sections may be considered prefatory to the following discussion. Many of the photometric data were obtained for the purpose of placing this type of airplane camouflage on a scientific basis. Such work should not be left to judgment based upon limited qualitative visual observations because the final efforts must necessarily be compromises aimed to strike the mean. Only definite measurements can establish such mean values.

Airplanes whose chief activities are carried on at low altitudes predominantly over friendly territory, such as may be the case in

certain patrol operations, would ordinarily be in danger chiefly from enemies overhead. Such aircraft can be camouflaged successfully for low visibility as viewed from above. The earth is the usual background, although in the case of low clouds these would sometimes be below such airplanes; however, clouds would often serve as a screen. Sunlit clouds are many times brighter than the earth as shown in Section 7. Although they vary in brightness, their sunlit sides are of the order of magnitude of ten times the mean earth brightness. Owing to this fact camouflage cannot be successfully worked out on the same airplane for both earth and cloud backgrounds. Furthermore, the earth is the background that is overwhelmingly present and, therefore, it is the one which will be considered in the present discussion.

The various types of areas of the earth's surface, such as woods, fields, water, and barren land, differ somewhat in relative brightness or in apparent reflection-factors, although their mean values were found to be quite constant and not very different on various days as seen in Table I and other tables. They also differ in pattern and hue; however, brightness is the most important factor. When the observer is at great heights or distances, pattern becomes of relatively little importance owing to the fact that the airplane appears scarcely larger than a speck. When he is at high altitudes or great distances the importance of color also diminishes to a small degree. However, the importance of brightness persists until the camouflaged airplane dwindles beyond a minute speck or until it is otherwise invisible.

It is quite obvious if the investigation of camouflage of the type under consideration at present is left to judgment by experimenting with various colors on airplanes, the best practice could not be determined with certainty. For example, an airplane provided with a pattern of certain hues and reflection-factors, might be fairly inconspicuous over a wooded area and be quite conspicuous over ploughed or barren land. Furthermore, if no measurements were applied, our experimentally camouflaged craft would be either visible or invisible in the absence of a scale of visibility. As a matter of fact, all experimental craft would doubtless fall in the "visible" class. Visibility scales could be established by using a neutral absorbing wedge or a series of absorbing screens arranged in steps according to their transparen-

cies. An instrument might be utilized which would introduce a luminous haze or veil and the intensity of the luminous veil required to render the craft invisible might be taken as a measure of its visibility. These methods were tried more or less incidentally to illustrate the difference in the visibilities of aircraft painted differently, but inasmuch as such experiments involve the disadvantage of requiring extended aerial sojourns above the camouflaged craft by a number of observers, they were not considered practical. This decision was also hastened when it became evident that the mean relative brightness or reflection-factor of the earth and its typical areas could be determined by means of photometric apparatus. After such values were obtained it would be an easy matter to provide an airplane with a coating of proper reflection-factor. The mean hue could also be obtained but it early appeared evident that this could be satisfactorily approximated by certain methods based primarily upon a fair knowledge of the earth's coloring. The pattern could also be determined fairly satisfactorily as is illustrated in Section 14.

The high visibility of airplanes of yellowish-white finish viewed against the earth as a background is very evident even to a casual observer. This is well illustrated in Figs. 8 and 20. The earth background, including the barren and ploughed areas, are much darker than the uncamouflaged craft. This is quite evident in Figs. 8 and 20 for the wooded area, but the limitations of photography are somewhat misleading for the brighter areas. Of course, in the rare case of viewing an airplane against a cloud background, the visibility of the airplane with light finish is lower than a craft with a very dark finish. However, the clouds would more often form a screen from the enemy for low-flying craft whose operations would ordinarily be confined below the ordinary altitude of cumulus clouds. The airplane shown in Fig. 8 was about 200 feet below the photographer. As the distance of the craft increases, its size very rapidly diminishes. The earth shown in this illustration was about 6000 feet below the camera. It is seen in this illustration that a pattern, which aimed to simulate the irregular checkerboard pattern of cultivated fields, if applied to an airplane, would consist of only one or at most two or three areas on the entire airplane. In order not to be confused at this point, the reader should refer to Section 14 in which pattern is discussed at length. For reasons discussed in that section it

FIG. 20.

Showing approximate brightness relations of uncamouflaged airplane, clouds and landscape.

appears that one of the most desirable patterns which could be used would be that which simulates woods. Notwithstanding the values of apparent reflection-factor which are available in Table I, the best value of the mean reflection-factor for a camouflaged airplane depends somewhat upon the basis for adopting the particular pattern. For example, if the simulation of woods were chosen, the mean reflection-factor would perhaps be best if it were close to that of wooded areas in summer, namely, about 4 or 5 per cent. The size of the pattern might best be adjusted for an airplane 5000 feet above the earth and 5000 feet below the observer. Clumps of trees are common in most landscapes so this pattern appears feasible although, of course, the shape of the craft would contribute somewhat toward its detection. Inasmuch as the airplane is likely to be viewed at distances of several thousand feet predominantly, the pattern would approach full size; that is, it would be rather large. It would be made by using a very dark shade of green for the highlights and a bluish black for the shadows. No artistic painting would be necessary.

Referring to the mean values in Table I we have the apparent reflection-factors for various types of areas, namely,

Woods	0.043
Fields	0.068
Barren land	0.13
Inland water	0.068

In the original report the colors of these respective brightnesses and aproximately correct hues were shown, but it is impracticable to do so here. If a pattern were to be adopted which contained areas simulating the hues and brightnesses which were determined, the desired proportions of this could be used. I do not favor such a pattern (represented in Fig. 19) because, the airplane being a moving object, is readily distinguished by the moving brighter areas as the craft sails over the darker areas of landscape. The movement of darker objects over the brighter areas is not generally as noticeable; at least this appears to be true for the range of brightnesses with which we are concerned. One of the chief obstacles in the use of such definite and contrasty patterns is the fact that the camouflaged craft is moving.

Solid or uniform color over the entire plane is not fully satisfactory because the background is never perfectly uniform except

over water. Therefore, there is some compromise which is the best pattern. As seen in Section 14, with the exception of woods, crops, etc., the earth's pattern is entirely too large to be simulated on an airplane. This leaves us scarcely any other pattern except a mottled one of large indefinite figures. A very subdued pattern is more promising than such a one as Fig. 19. In fact, according to the values in Table I, the mean reflection-factor of any successful pattern must be very low. Ordinary commercial "black" paints often reflect as much as 0.03 of the incident light, so it is seen that the mean brightness of the earth approaches that of "black" paint under the same illumination.

If the mean apparent reflection-factor and mean hue of a certain landscape are desired, these can be obtained approximately by estimating or determining the proportions occupied by the various areas and using the mean values in Table I. For example, the following would be the procedure for one region among those studied at the particular period of the year:

Area.	Apparent reflection-factor.	Portion occupied.	Total contribution.
Woods	0.043	0.40	$.043 \times .4 = .0172$
Fields	0.068	.30	$.068 \times .3 = .0204$
Water	0.068	.10	$.068 \times .1 = .0068$
Barren	0.13	.20	$.13 \times .2 = .026$
Mean			.07

The mean apparent reflection-factor of this landscape is therefore approximately 0.07. This is shown in color in the original report. A circle is divided into sectors corresponding to the proportions of the total area occupied by the different types of area respectively. These sectors are painted with paints of corresponding reflection-factors and approximate hues. When this color-wheel is rapidly rotated the mean color and reflection-factor is obtained. The mean color in this case is a very dark greenish gray.

It is impracticable to carry this work further in this paper. The essential details, measurements and limits have been established and they may be readily combined to meet the conditions of the landscape which will actually form the background for airplanes viewed from above. With the data in this paper it is possible to develop camouflage for other seasons of the year

which should be satisfactory in practice. In winter it should be easy to copy the landscape in a country where snow lies on the ground. Barren spots can be directly copied with the aid of the measurements herein recorded and the snow can be simulated by white paint. Where snow predominates it would appear best to paint the airplane a dead white on the upper surfaces. It would thus be of extremely low visibility over snow-covered areas, and even though visible over barren areas it would become of low visibility to the enemy again as it passed between a snow area and the enemy. It is surprising how difficult it is to keep an airplane under observation if it is colored to simulate even a portion of the landscape. The angular extent of the visual field is so limited that despite the efforts of the pilot, his view or that of the observer, is often interrupted by the wings and body of the craft. These are practical conditions which help to make camouflage feasible for airplanes.

In this type of camouflage it is advisable to use a matte or flat paint. It would also be feasible to incorporate the coloring media in the approved varnishes, but unfortunately these are glossy. Obviously it is essential to use vehicles which do not attack the dopes and varnishes already approved for airplane fabric. These are problems concerning which information is available and they can be readily met.

Of course, some consideration must be given to insignia. Instead of two, one on each wing, these might be reduced to one; in fact, they might be confined to the sides of the fuselage and lower sides of the lower wings. I have been told that ships are recognized as to nationality by other distinguishing features. Surely insignia are practically useless at a distance of a few thousand feet. At any rate, the white area could be reduce to a gray. Considerable attention was given to this problem and it offers no discouragement.

16. VISIBILITY OF AIRPLANES AS VIEWED FROM BELOW.

In this case the sky and clouds form the background, and in order to achieve complete invisibility the lower surfaces of the airplane must be rendered equal in color and brightness to the background. An obvious ideal would be an airplane of complete transparency so that the background could be viewed through the transparent media, unaltered in color and brightness. This con-

sideration led to experiments on transparent or partially transparent media. After some experiments it appeared that a partially transparent fabric could be obtained by incorporating a fabric or coarse mesh in a transparent medium such as "celluloid" or gelatine. However, perfect transparency cannot be realized and various practical considerations led to a less sanguine view of such an application. For example, there is much opaque material in an airplane and the projected area of this opaque material rapidly increases in percentage of the total projected area of the airplane as the angle of view becomes more and more oblique to the craft. Another point worthy of consideration is that even a sheet of clear glass has a transmission-factor of not more than 0.92 and it is not expected that a practicable fabric could be devised which would have a transmission-factor exceeding 0.5. From the standpoint of invisibility, as viewed from below, it is desirable to use as transparent or translucent material as possible and to employ colorless dope and varnishes. Bleached linen, white silk, and cotton would be better than the yellowish unbleached linen from the present point of view. Ordinary airplanes with yellowish finish are at present conspicuous against a blue sky on a sunny day not only on account of their much lower brightness but also owing to their distinctly yellowish color. This must be corrected to the unsaturated blue of the sky.

Of course some of the brightness of the lower surface of an object in the air is due to the light reflected by the earth to it, but this is a small part of its total brightness if the object is fairly diffusely transmitting. The limits of this additional brightness contributed by the reflection of the earth's surface can be computed by assuming the conditions of an overcast day and a clear day respectively. For the sake of clearness let us assume first a horizontal diffusely reflecting opaque object in the air on an uniformly overcast day. If the average reflection-factor of the earth is 0.1, the lower surface of the diffusely reflecting surface will have a brightness of $0.1\,RB$, where R is the reflection-factor of the object and B is the brightness of a uniform sky. In other words, a perfectly white diffusely reflecting opaque object under these conditions could not be more than one-tenth the brightness of the sky; that is, the limiting brightness is dependent upon the average reflection-factor of the earth. It will be seen that an airplane or any opaque or translucent object is more generally

conspicuous when viewed against the sky on an overcast day than on a clear day.

Assuming on a clear day that the sun contributed 0.8 of the total light which reaches the earth, then the earth's average brightness will be 0.5 B if its mean reflection-factor is 0.1 and B is the brightness of the sky. The brightness of the lower surface of a perfectly white diffusely reflecting opaque object will now be 0.5 RB where R, as before, is the reflection-factor of the lower surface. In other words, the object under these conditions will be less conspicuous when viewed against the sky on a clear day than on an overcast day. Assuming $R = 0.8$, which is a value obtainable with so-called white pigments, then the ratios of the brightness of the lower surface of the horizontal opaque object to that of the sky will be

$$\frac{0.1 \times .8 \times B}{B} = 0.08 \text{ on an overcast day, and}$$

$$\frac{0.5 \times .8 \times B}{B} = 0.4 \text{ on a clear day,}$$

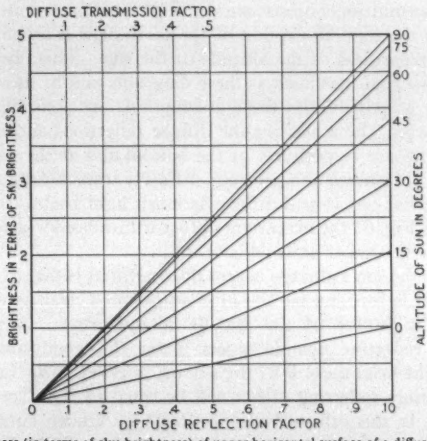
with the conditions as assumed. In the two cases B might not be the same but its absolute value is of little consequence. Contrasts are the important factors in visibility. Obviously, if the reflection-factor of the earth were unity (a perfect white) the brightness of the lower surface of the diffusely reflecting object would be much greater. Under these conditions, if $R = 1$, the object would be as bright as the sky on an overcast day and 5 times the brightness of the sky on the clear day under the conditions assumed.

The foregoing analysis touches merely a few salient points for the purpose of indicating the phases to be considered. It is seen that, on the sunny day assumed, a diffusely transmitting medium would be of about the same brightness as the uniform clear sky at noon if its transmission-factor were 0.4, without taking into account the effect of light reflected upward from the earth. On sunny days translucent media of proper tint generally would be more satisfactory than transparent media for airplanes because of the direct contribution of light by the sun. On overcast days the advantage would be with the transparent medium; however, it appears quite possible that in consideration of all practical aspects a diffusing medium of fairly high transmission-factor

and bluish tint would be more generally satisfactory than the partially transparent medium. Furthermore, on overcast days the clouds are usually so low that high-flying airplanes would be far above them.

Let us consider the possibilities obtainable with opaque material for the wings but painted with diffusely reflecting coatings and also those obtainable with translucent fabrics which are diffusely transmitting. A few diagrams will illustrate the range of practical possibilities. Some of the discussion pertaining to Figs. 1

FIG. 21.



Brightness (in terms of sky-brightness) of upper horizontal surface of a diffusely reflecting object and of lower horizontal surface of diffusely transmitting object under various conditions. Sun contributes 0.8 total light at midday; sky of uniform and constant brightness.

to 7 will serve as an introduction to the discussion which follows. Obviously it would be futile to attempt to analyze the conditions for an average sunny day when there are numerous clouds in the sky, so that only skies of uniform brightness will be discussed for a complete range from an overcast day to a very clear day. On this basis any object is illuminated by light from the uniformly bright sky and by direct light from the sun which varies with the altitude and with the clearness of the atmosphere. Direct sunlight scattered by the atmosphere makes its contribution toward the illumination of an object as light from the sky.

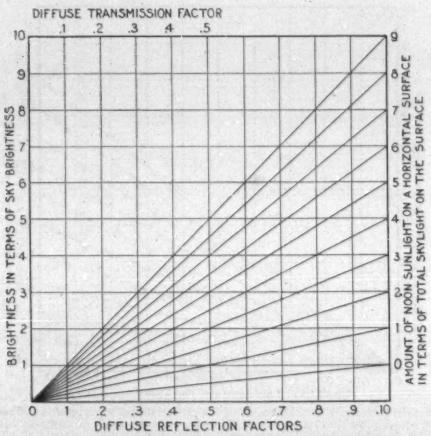
In Fig. 21 the sky is assumed to be of uniform and constant brightness throughout the day and 0.8 of the total light which reaches the earth at midday is assumed to come directly from the sun. The latter assumption is a fair average for clear days although the value is greater on days when the sky is deep blue in color (very little haze) and is lower on very hazy days. The sky-brightness equals B and the relative brightnesses of the upper surface of diffusely reflecting opaque objects (of various reflection-factors) are determined in terms of B for various altitudes of the sun. The relative brightnesses of the lower surface of diffusely transmitting objects are considered simultaneously. For simplicity the total absorption of the earth haze is assumed to be constant regardless of the altitude of the sun. This obviously is not the case, but inasmuch as these diagrams aim to show merely the range of possibilities these assumptions are considered to be satisfactory. The scales for the diffuse reflection- and transmission-factors are respectively at the bottom and at the top of the diagram. Inasmuch as a perfectly diffusely transmitting and non-absorbing flat object will diffuse as much light backward as forward (see Fig. 6) the maximum diffuse transmission-factor is 0.5. Therefore the upper scale ends at 0.5.

When the sun's altitude is zero the condition is that of an overcast day or before sunrise and after sunset on a clear day (assuming the brightness of the sky to be uniform). A perfectly diffusely reflecting opaque object under this condition will be equal to the brightness B of the sky or, in general, the brightness of a diffusely reflecting object will be equal to RB (see Fig. 6) where R is the diffuse reflection-factor. Under similar conditions, the transmission-factor being equal to T, the brightness of the lower side of a diffusely transmitting object will be equal to TB. The brightness of a perfectly diffusely transmitting object ($T = 0.5$) under a sky of uniform brightness B will equal $0.5\ B$ whether viewed from above or below, whereas the brightness of the upper surface of a perfectly diffusely reflecting object ($R = 1$) will equal B. These facts are indicated in Fig. 21. Inasmuch as we are primarily concerned with diffusely transmitting media in the present discussion, the upper scale is of chief importance. The area representing the conditions under which a diffusely transmitting object may be brighter than the sky background can be readily isolated on the diagram. At midday it is seen that

a horizontal diffusely transmitting medium, with $T = 0.2$, will appear of the same brightness as the sky when viewed from underneath. No contribution of light reflected upward from the earth is considered in this diagram.

A somewhat similar diagram is shown in Fig. 22, except that the condition is assumed to be midday (sun's altitude 90 degrees) and the sun is assumed to contribute various proportions of the total light which reaches a horizontal surface. The scale for the

FIG. 22.

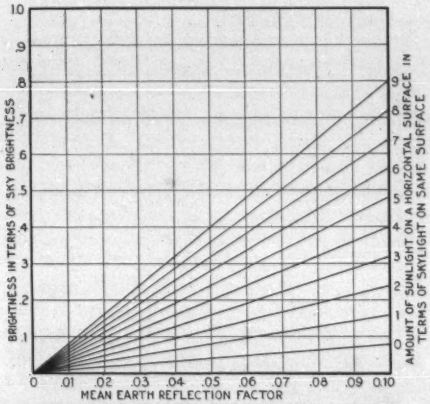

DIFFUSE TRANSMISSION FACTOR
.1 .2 .3 .4 .5
BRIGHTNESS IN TERMS OF SKY BRIGHTNESS
AMOUNT OF NOON SUNLIGHT ON A HORIZONTAL SURFACE IN TERMS OF TOTAL SKYLIGHT ON THE SURFACE
0 1 .2 .3 .4 .5 .6 .7 .8 .9 .10
DIFFUSE REFLECTION FACTORS

Brightness (in terms of sky-brightness) of upper horizontal surface of diffusely reflecting object and of lower surface of a diffusely transmitting object under various conditions. Sun at zenith and contributing various times as much as sky which is of uniform brightness.

latter is on the right of the diagram where it is seen that the diagram covers the conditions when the sun contributes from zero to 9 times the amount of light contributed by the uniform sky upon a horizontal surface. This range represents practically the entire range of proportions measured at the earth's surface. As indicated in a previous section, this proportion greatly increases at high altitudes. On the diagram the area representing the range in which the under side of diffusely transmitting objects may be brighter than the sky background is readily distinguished. How-

ever, there is some light contributed to this under side by reflection from the earth. For simplicity the mean reflection-factor of the earth may be assumed to be 0.1 and ½ of the light which it reflects upward to the diffusely transmitting object may be assumed to be diffused downward from the diffusely transmitting medium. This contribution due to reflected light from the earth would slightly extend the region on the diagram in which the brightness of the under side of the diffusely transmitting object

FIG. 23.



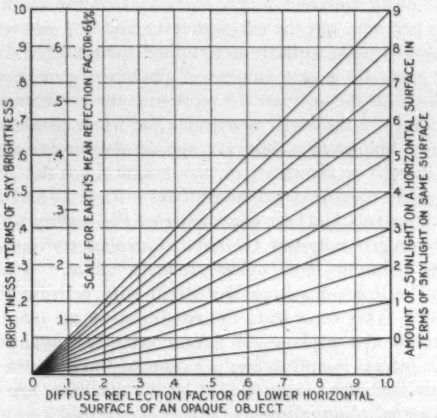
Brightness (in terms of sky-brightness) of lower horizontal surface of a diffusely reflecting opaque object whose reflection factor is 0.8. Time is midday, sky is uniform in brightness, and sun is assumed to contribute various proportions of the total light.

is brighter than the sky background, but it is not shown in the diagram.

In Fig. 23 another aspect is analyzed, namely, the brightness of the lower horizontal surface of an opaque object painted with a commercial flat white pigment possessing a diffuse reflection-factor of 0.8. The natural lighting conditions are assumed to be a sky of uniform brightness with the sun contributing from zero to 9 times the amount of light that reaches the earth from the sky. The light which reaches the earth is partially reflected upward depending upon the mean apparent reflection-factor of the earth. According to photometric measurements the portion of

the total reaching the earth which is reflected upward lies between 0.05 and 0.1 for summer landscape in fertile countries. It is seen that under the range of conditions assumed, the lower surface of the horizontal object which is painted with the commercial flat white cannot be as bright as the sky. Inasmuch as this range includes the best conditions that could be expected, low visibility as viewed from below, cannot be realized for low altitudes by

FIG. 24.


BRIGHTNESS IN TERMS OF SKY BRIGHTNESS
SCALE FOR EARTH'S MEAN REFLECTION FACTOR-6¼
AMOUNT OF SUNLIGHT ON A HORIZONTAL SURFACE IN TERMS OF SKYLIGHT ON SAME SURFACE
DIFFUSE REFLECTION FACTOR OF LOWER HORIZONTAL SURFACE OF AN OPAQUE OBJECT

Brightness (in terms of sky-brightness) of lower horizontal surface of a diffusely reflecting opaque object illuminated by light reflected upward from the earth at midday. Scale on left for two reflection factors of earth, namely 10 and 6¼ per cent. respectively. Various proportions of direct sunlight assumed and sky is uniform in brightness and equal to unity.

painting the under sides of an airplane an opaque white. The reflection-factor of aluminum paint is less than that of a good white but its reflecting characteristics are somewhat different, so that it tends to lower the visibility when the airplane is viewed at certain critical angles. Of course the haze tends to lower the visibility by operating as a veil. Furthermore, as the aircraft ascends to high altitudes, the sky-background becomes less bright and the lower surfaces receive more light due to the contribution of upward light by the clouds if any are present below the airplane. Furthermore the visibility decreases somewhat owing to the decrease in the size of the image. These

combined reasons account for the fairly low visibility of some ordinary aircraft at very high altitudes on very clear days. The contribution of light reflected by the earth to the lower surfaces of an airplane can be taken from this diagram and added to the values in the preceding diagrams.

A similar analysis is found in Fig. 24. The bottom scale represents a complete range of diffuse reflection-factors of the lower horizontal surface of an opaque object. Two scales on the left represent mean apparent reflection-factors of the earth, respectively 10 per cent. (at the extreme left) and 6⅔ per cent. The latter value is close to those determined for water and fields of growing crops by a vast number of photometric measurements. The region near the ordinate 0.8 represents the brightnesses of the lower surface if the best commercial flat white paints are used. As already indicated, a fair average of the sun's contribution of light directly is about 0.8, or about four times the amount of skylight when measured at low altitudes. Figs. 23 and 24, based upon photometric data, are convincing of the futility of attempting to obtain generally low visibility of airplanes as viewed from below by painting their lower surfaces white. Attention is called to the line connecting the origin with zero on the right-hand scale. This represents the condition on an overcast day. It is seen that the airplane will appear very dark against the sky for its brightness is only a few per cent. of the brightness of the sky. This and other facts yielded by the diagrams are corroborated by actual observation.

The practical solution of low visibility for airplanes as viewed from below must include means for increasing the brightness of the lower surfaces. Possibilities which suggest themselves are more diffusely transmitting fabrics and artificial illumination.

At this point it is of interest to discuss further the reasons for the low visibility of some airplanes at very high altitudes when viewed against the sky. In the absence of cirrus clouds, the sky appears much darker when viewed from a position above the earth haze whose upper surface varies in altitude usually in the neighborhood of 4000 to 6000 feet. As we ascend above this the sky usually becomes less and less bright. At very high altitudes the background against which the airplane is viewed is considerably darker than at low altitudes. This tends toward lower visibility for the airplane.

At these high altitudes the amount of light reflected or emitted upward against the lower surface of a horizontal plane approaches the amount contributed by the sky. Then if this lower surface possessed a high diffuse reflection-factor (approaching unity) its brightness, due to light directed upward, would approach the brightness of the sky. This tends toward lower visibility for the airplane at great heights. It is seen that, as the airplane approaches high altitudes, a lower value of diffuse transmission-factor will suffice to render it as bright as the sky. In fact, at high altitudes where the sun contributes a large portion of the total light, a diffusely transmitting fabric has great possibilities. An opaque reflecting surface is taxed to the extreme even at these highest altitudes.

The difference in color between the airplane and the sky (even when the former is white) is responsible partly for the visibility of airplanes at these very high altitudes. This could be overcome by means of a bluish tint in the diffusely transmitting fabric, but tinting a diffusely reflecting surface sufficiently to overcome this difference in color would lower its reflection-factor considerably so in order not to reduce the brightness of the lower surfaces of the airplane much below that of the sky, the fabric must be fairly translucent initially.

Finally, the ever-present haze which is a luminous veil tends to lower the brightness contrast and the hue contrast and thus to lower the visibility. These measurements and various other considerations lead again to the conclusion that very low visibility for airplanes viewed from below can be obtained by using highly translucent fabric of a proper tint. At extremely high altitudes where the sky is dark and the veiling haze is helpful, airplanes whose lower surfaces are coated with white or aluminum are sometimes of low visibility. At lower altitudes this certainly is not true as ordinary observation shows.

Airplane wings, consisting of two sheets of cloth separated by a distance of one to a few inches and covered with coatings such as varnish which are far from colorless, are of very low transmission-factor at present. Of course an airplane camouflaged for view from above by means of colored paints would have left none of the advantages of transparency or translucency aimed to render the airplanes invisible from below. However, two entirely distinct classes of service are in mind in considering

these two opposite views. The airplane which would require low visibility from beneath would be one whose duties took it especially high so that enemies would ordinarily be beneath. But these are aspects outside the scope of the present discussion. However, from various analyses it appears that sufficient translucency can be obtained by the use of proper fabrics and varnishes. This point will be discussed later, but it is of interest to discuss the possibilities of artificial illumination. This does not appear either promising or feasible but an analysis will be worth while.

In the application of artificial light various ideas have been considered. Small lamps might be placed inside the wings between the two layers of cloth. By painting the upper sheet an initial coat of white, the effects of camouflage on the upper surfaces would be nullified if it were desirable to camouflage the same craft for low visibility as viewed both from above and from below. It might be possible to use a white translucent fabric for the upper sheet of a wing and a transparent or partially transparent fabric for the lower sheet of the same wing. There are advantages from the standpoint of efficiency of utilizing the artificial light in an enclosed space. Of course the advantages over exposed lamps are evident at once from the standpoint of head resistance. Lamps could be suspended somewhat below the wings and equipped with small reflectors; however, there are very great disadvantages in thus exposing them. The lower sides of the airplane could be studied with incandescent filament lamps or projectors could be fastened on the running gear. All of these cases of exposed lamps and equipment have the great disadvantage of increasing head resistance. High speed generators have been considered for the generating equipment and storage batteries for experimental work if the former were not available. Computations, however, do not yield encouragement.

Artificial Lighting.—Before discussing equipment some rough computations will be presented to indicate the wattage of incandescent lamps which would be required. The brightness of the sky varies usually between 0.5 to 2 lamberts, one lambert being a fair average. Assuming first that we have a perfectly diffusely reflecting white surface to be illuminated to a brightness of one lambert. The brightness of such a surface is equal to one lambert when each square foot of the surface emits 929 lumens. If the

reflection-factor is equal to R, the surface must receive $929/R$ lumens per square foot. For each 100 square feet of surface painted with a white diffusely reflecting coat having a reflection-factor of 0.8 (which is about the best that could be maintained in practice) there would be required $\frac{929 \times 100}{0.8}$ lumens, or about 116,000 lumens. The rated efficiencies of the incandescent lamps used depend upon their wattage and voltage, but for this purpose it would be justifiable to operate them considerably above their normal efficiency. Assuming an efficiency of 20 lumens per watt it would require 5800 watts to supply the 116,000 lumens provided all the lumens generated were directed upon the 100 square feet of surface without loss which, of course, could not be realized. Assuming a loss of 40 per cent. it would be necessary to increase the wattage to about 9700 watts. The amount of light contributed by the earth to the under sides of the airplane depends upon the season of the year, being very high when the earth is snow covered. However, during a large portion of the year the light reflected by the earth would contribute a brightness to the lower side of the plane of the order of magnitude of 0.1 B on an overcast day (where B is the brightness of the sky), and of the order of magnitude of 0.5 B on an average clear day. Owing to the extreme variations in natural lighting these figures can be considered as being only very roughly approximate. Based on these estimates the foregoing value of 9700 watts could perhaps be reduced to about 5000 watts on an average clear day. Assuming other contributions of light to the lower sides of the airplane, this can be materially reduced in practice. The lower side of the upper plane is always brighter than the lower side of the bottom plane, due to the reflected light from the upper side of the bottom plane and also to the fact that the upper plane intercepts light which would otherwise fall on the lower plane.

The foregoing wattage estimates are for 100 square feet. The lower surfaces of airplanes are greater in area by at least three times so that the minimum estimate of 5000 watts would be increased to a total of 15,000 watts. These computations are based upon a brightness of one lambert. If the brightness of a very clear blue sky is assumed to be 0.5 lambert, the wattage required would be reduced to 7500 watts for the 300 square feet area.

It is understood that these computations are based upon certain measurements and estimates of average conditions and, therefore, aim to represent only the order of magnitude of the factors involved. It does not appear that the requirement could possibly be reduced below several thousand watts, but the generation and distribution of this wattage presents a very serious problem on ordinary airplanes. If only the very high altitudes are to be considered, it appears that the lower estimates of wattage would be sufficient.

Data on storage batteries are available and the following estimates are based upon information furnished by the Willard Storage Battery Company:

> From an 80 amp-hr. automobile storage battery we obtain,
> 10 amperes for 8-hour discharge rate.
> 40 amperes for 1-hour discharge rate.
> 80 amperes for 20-minute discharge rate.
> These are 1.5 volt cells.

The proper type of lamp can be easily obtained for any voltage but for the sake of discussion the 80-ampere discharge rate will be assumed. For 2000 watts, 25 volts would be required at the 20-minute rate. This voltage would require 6–3 cell batteries at 1.5 volts per cell. The weight is 55 lbs. per 3-cell battery or 330 lbs. for the total capacity of 2000 watts at 25 volts for 20 minutes. This weight could be materially reduced for experimental purposes because observations of only a few minutes at a time would be sufficient. It could replace the observer in a two-passenger airplane and thus the experiments might be conducted with storage batteries. However, it will be noted that the previous estimates indicate that perhaps as much as 7500 watts would be necessary in order to be practicable under certain conditions. Assuming a miniature Mazda No. 146, 18–24 volt, 1 ampere lamp, taking about 25 watts average on above battery, about 40 lamps of this type would be required per 1000 watts. The disposition of these lamps adds another difficulty to that of weight of generating equipment and air resistance, so that the realization of invisibility as viewed from below by means of artificial light appears to be a remote possibility. Color correction could be easily obtained.

A more practical generating equipment would be a high speed, 100-volt generator. The Fort Wayne Works of the General

Electric Company submitted the following weights of turbo-generators:

2 kw.	115 lbs.
3 kw.	140 lbs.
5 kw.	275 lbs.

Doubtless the weight of these could be materially reduced by using aluminum for some of the parts. The use of such turbo-generators of high speed, 3600 RPM., appears feasible for experimental work; however, a more promising and practical solution lies in giving attention to greater translucency in the fabrics and varnishes used on airplanes.

Translucent Fabrics.—There are few available data on the diffuse transmission-factors of fabrics. The data on diffusing glass convinces us that high diffusion is not incompatible with high diffuse transmission. Perfectly diffusing opal glasses have transmission-factors as high as 0.4 to 0.5. Textiles differ greatly in the transparency of the threads, silk fibres being much more transparent than cotton or linen as is seen by photomicrography. At present unbleached linen is largely being used for airplanes. This not only possesses a slightly lower diffuse transmission-factor than the bleached linen but is responsible for a yellowish tint which is undesirable owing to its high visibility against the blue sky.

If white fabrics could be impregnated with a liquid which would render them more translucent, this would be a solution. However, bluish-white linen or cotton fabrics would contribute considerably toward low visibility if colorless varnishes were used. Measurements on prepared samples indicate that the diffuse transmission-factors of double sheets, separated somewhat as in an airplane wing, are great enough according to the diagrams (Figs. 21 to 24). If bleached linen or white cotton fabric were used with colorless dopes and varnishes, a considerable step will have been made toward low visibility as viewed from below. It is an easy matter to investigate the possibilities of fabrics after they have met the requirements as to strength.

Although photographic evidence is not as satisfactory as that afforded by direct visual observations and measurements, photographs aid in visualizing conditions described in this report. Any airplane at present is ordinarily a dark object when viewed against the sky even on a clear day. This is well illustrated in Fig. 25.

On overcast days it is very dark relative to the sky. Even though the exposure was insufficient to show the earth in its true value, the airplane appears very dark. Of course the limited contrast range obtainable by means of photography is often misleading, but this photograph illustrates a common condition.

Fig. 26 indicates the condition again except that the upper surfaces of the airplane are visible against the sunlit clouds. Even

FIG. 25.

An airplane is ordinarily a dark object against the sky.

these upper surfaces which receive both sunlight and skylight are darker than the clouds. These airplanes were finished the natural yellowish white. Although the reflection-factor of this natural yellowish finish is variable and very glossy, its mean is in the neighborhood of 0.35 to 0.45. This is much less than the apparent reflection-factor of sunlit dense cumulus clouds. If bleached linen or white cotton fabrics and colorless dopes and varnishes were used the upper surfaces of the wings would be about as bright as the sunlit clouds.

Although clouds sometimes form the background against which airplanes are viewed it is hardly practicable to consider

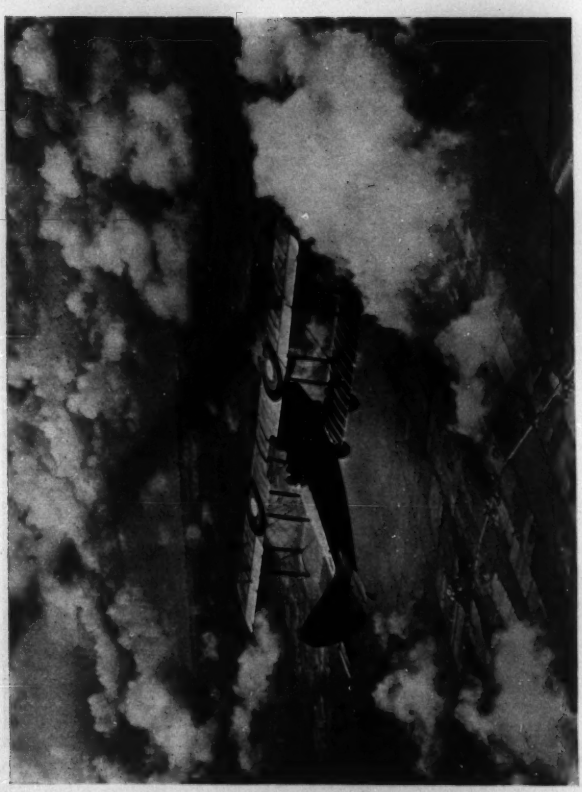


FIG. 26.

Airplane viewed against clouds.

FIG. 27.

Airplane viewed against a bank of cumulus clouds.

them. They are generally so overwhelmingly bright in comparison with either the sky or the earth that successful camouflage cannot be provided for both earth and cloud backgrounds on the

TABLE VI.

Brightnesses of Four Samples of Airplane Fabrics (Linen) in Terms of the Brightness of Zenith Blue Sky. The Day was Cloudless with the Exception of a Few Cirrus Clouds Near the Horizon; the Zenith Sky was Deep Blue with no Suggestion of a Haze; and the Sun was at 45 Degrees Altitude. The Sky Contributed ¼ of the Total Light Reaching the Earth. The Fabrics were Stretched Horizontally About 4 Feet Above a Large Plot of Green Grass.

Sample.	Relative Brightness.			
	No. 1	No. 2	No. 3	No. 4
One layer, upper side	7.1	4.9	3.5	6.5
One layer, lower side	3.6	2.0	1.05	3.3
Two layers (2 inches apart), upper side	6.8	5.2	3.6	5.0
Two layers (2 inches apart), lower side	1.5	0.66	0.36	1.05
Horizontal perfectly white diffusing surface	14.35	14.35	14.35	14.35
Zenith sky	1.0	1.0	1.0	1.0

TABLE VII.

Brightnesses of Four Samples of Airplane Fabrics (Linen) in Terms of Perfectly White Diffusing Surface (Horizontal) Receiving Full Sunlight and Skylight.

Sample.	Relative Brightness.			
	No. 1	No. 2	No. 3	No. 4
One layer, upper side	50	34	24	45
One layer, lower side	25	14	7	23
Two layers (2 inches apart), upper side	47	36	25	35
Two layers (2 inches apart), lower side	10	5	3	7
Horizontal perfectly white diffusing surface	100	100	100	100
Zenith sky	7	7	7	7

same airplane. The same is true of sky and cloud backgrounds. Fig. 27 illustrates the variable brightness of a cloud background and again emphasizes the fact that the airplane of to-day is usually a dark object as viewed against sky and clouds.

As an illustration of the possibilities of translucent fabrics in obtaining low visibility for airplanes as viewed from below, let

us examine the results obtained with a sample of unbleached linen fabric of medium weight. A frame was supported in a horizontal plane about four feet above a grassy plot of ground by means of four thin legs. The day was cloudless, the sky was somewhat hazy but not uniform in brightness, and from the position of the experiment, practically the entire hemisphere of clear sky was visible. The altitude of the sun was about 60 degrees. The following are the relative brightnesses determined by means of a photometer:

Zenith sky	1.0
Lower side of one sheet of unbleached linen	2.3
Upper side of one sheet of unbleached linen	3.7
Lower side of two parallel sheets 2 inches apart	1.2
Upper side of two parallel sheets 2 inches apart	4.1
Upper side perfectly white diffusely reflecting surface	7.4

The relative brightness of the sky near the horizon was about 1.5, but near the sun it was many times greater as is the case on hazy days. It will be noted that the fabric when viewed against the zenith sky appeared brighter than the sky, which shows that the fabric has sufficient translucency for the purpose under consideration. If the fabric were bleached and then tinted a proper blue it would be exceedingly satisfactory on clear days provided the translucency was not impaired by the dopes and varnishes.

Data obtained for four samples on a very clear day are presented in Tables VI and VII. The zenith sky was a very dark blue and much less bright than the other portions of the sky.

17. VISIBILITY OF AIRPLANES AT NIGHT.

A white airplane may be somewhat less easily distinguished against a moonlit sky than a black airplane; however, it appears that the chief aim is to avoid being picked up by the beam of an enemy searchlight. Fundamental principles of vision convince us that a black object will become invisible sooner than a similar white object as the illumination is decreased. This is easily verified by comparing white and black objects in various positions perpendicular to the beam from an ordinary automobile headlamp.

An airplane painted a dull or matte black was sent aloft with instructions to the pilot to cross the beam of the searchlight at various heights and to hover in the extreme outer regions of the

beam. When the airplane entered the more intense region of the beam it was plainly visible, but it disappeared strikingly suddenly as it passed into the less intense outskirts.

Unfortunately it was not considered feasible under the local conditions to have another airplane of regulation yellowish white finish enter the beam simultaneously with the black airplane, so it was sent aloft after the latter had landed. This airplane was more conspicuous than the black one in the intense region of the beam and was plainly visible in the outskirts of the beam where the black one could not be seen. Later only the left-hand wings of an airplane were painted black, the other wings being of the natural yellowish white. Observations on the craft sustained the former conclusions.

The result of the experiments combined with a consideration of the fundamentals of vision indicate the advisability of painting airplanes to be used at night, a matte black of best quality in order to render it more difficult for the enemy searchlights to locate them and to keep the beams directed upon them. Unless unforeseen practical considerations should mitigate against the use of the black coating, it appears that in its use there is nothing to lose but always the possibility of gain.

This argument is based upon the assumption that the searchlight is the most important consideration. Actual experience at the battlefront might modify the foregoing discussion, but from the information at hand it appears that the searchlight is the raider's primary enemy.

18. VISIBILITY OF SEAPLANES.

In Table I and in Section 9 certain data on the relative brightness of water or its apparent reflection-factor have been presented. These data are important when attempting to obtain low visibility for seaplanes as viewed against the water as a background. The mean value for inland water in Table I is 0.068. Fortunately this is of the same order of magnitude as a weighted mean of ordinary landscapes, so that a seaplane painted for low visibility over water would not be very conspicuous over a landscape except for its solid or uniform color. Pattern would not be desirable for seaplanes because areas of such size as would form the immediate background for seaplanes at various altitudes generally appear very uniform in brightness.

It would be easy to obtain a color of a proper hue by experiment, although photometric observations yield such data satisfactory to the colorist. The reflection-factor of a paint can readily be made approximately equal to 0.068. This is a very dark color and may appear to be surprisingly low in value, but the range of the mean values obtained under various conditions is seen to be from 0.044 to 0.091 in Table I for inland water. Of course individual observations were greater in value but rarely were they more than 0.1. An extremely muddy river yielded a value of 0.20, but this condition was very exceptional. The means in Table I represent a total of many hundred made on various types of days over rivers, the Chesapeake Bay, and other inland waters. The values are as a rule included in a surprisingly small range close to the mean value 0.068.

The lower surfaces of seaplanes could be coated with paints of a greater reflection-factor because they would be seen ordinarily against the distant water and sky which are generally of a higher brightness than the water viewed perpendicularly or nearly so.

The color of shallow water varies considerably, depending upon the character of the bottom, but generally possesses a dirty yellowish green color. Deep water is of a bluish green hue. Therefore a deep shade of blue-green possessing a reflection-factor of about 0.068 appears to be a generally satisfactory color if the airplane is to be viewed vertically downward over inland waters. Inasmuch as the water when viewed obliquely is considerably brighter than when viewed normal to its surface, it appears that a better compromise would be found in a paint of proper hue but with a reflection-factor in the neighborhood of 0.1 for inland-water backgrounds. As already noted the brightness of water viewed at an angle of 45 degrees is considerably greater, corresponding to a reflection-factor of about 0.15. Perhaps 0.08 would be a more satisfactory value, but this could be determined very readily by experiment. The effect of the greater relative brightness of water when viewed at the more oblique angles would be somewhat offset by the greater veiling effect of the haze at such angles. Furthermore, inasmuch as the paint would not be perfectly matte, the airplane would appear brighter when viewed obliquely than when viewed from directly above.

For this reason lower values of reflection-factor would perhaps be quite generally satisfactory.

As shown in Section 9 the relative brightness or reflection-factor of deep ocean water far from land was found to be 3.5 per cent. and for a deep channel in Chesapeake Bay near its mouth the reflection-factor averaged 4.9 per cent. when viewed perpendicularly.

19. CONFUSABILITY.

There appears to be little or no use for this type of camouflage for airplanes. Its use in marine camouflage is to confuse the submarine commander regarding the exact course, etc., of the intended victim. In aerial operations the speed is so enormously greater than in marine operations that the possibility of attaining any advantage in this manner appears very remote. It might be possible that certain gaudy or brilliant colorings would have some psychological effects upon the enemy initially, but the application of these will doubtless be more or less a matter of choice for the aviators. In order to establish the value of such patterns elaborate systematic experiments would be required with a number of observers. The value which we might hope to gain from such application does not appear sufficiently promising to warrant an extensive investigation.

An airplane covered with aluminum foil reflects direct sunlight very powerfully, which might be annoying to the enemy. When these direct reflections are absent such a plane is of low visibility under certain conditions. A disadvantage of this is the cost; however, it would appear to have the advantage of rendering the craft less inflammable.

A general disadvantage of "confusing" patterns is that the airplanes become very conspicuous. In fact, confusibility would not be obtained without conspicuity.

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Improved Treatment of Burns. ANON. (*Chemical and Metallurgical Engineering*, vol. xx, No. 6, p. 288, March 15, 1919.)—The war that has so recently closed has been no exception to those of the past in that all the medical and surgical arts were most intensively developed. Notable among the successes was the treatment of burns by Barthe de Sandfordt, who had spent sixteen years in trying to overcome the prejudices of the medical fraternity to his closed wax seal treatment. It was only when the hospital at Issy les Moulineaux was filled with many patients suffering with burns that it was considered advisable to depart from the usual practice and prove out this method experimentally.

The paraffine wax composition, called ambrine by de Sandfordt, is sprayed on the wound at 140–150° F., and the absorbent cotton is plied on alternately with wax layers. The aggregate of wax and cotton seals the wound and thermally insulates it as well, the temperature of the ambrine at the skin being found to be 106° F. for several hours after each 24-hour dressing. This method is actually a case of incubation, wherein the flesh and skin cells propagate themselves in a most remarkable manner. However, all infection and bacteria must be excluded if present by some such means as Dakin's hypochlorite solution with Carrel's technic, or the incubation of flesh and skin cell destroying bacteria will result, with the balance sheet showing nothing but loss. Fresh burns, being sterile, of course, are ideal for the ambrine treatment, and it has been with them that the most marvellous cures have been made.

The warm dressing has an additional virtue in that it draws the fire instantly from the wound and allows the patient to become normal. Dr. R. C. Casselberry treated the 75 employees burned at the Essington, Penna., powder explosion and reported the advantages of the ambrine treatment as: relief from pain to a great degree; cleaner and more comfortable; fewer scars and contractions; skin grafting rare; more rapid healing; superior in every way to other methods commonly used.

The army surgeons have had such marvellous success with ambrine in treating all sorts of burns that it became necessary to establish the Ambrine Laboratories, 347 Madison Avenue, New York City, to supply the demand. All manufacturing plants dealing with hot materials and having frequent burn accidents will do well to become acquainted with the results reported in the current medical literature.

THE COLOR OF WATER.*†

BY

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"Bunsen was the first to deny that water was colorless. Struck by the greenish-blue tint of the hot water of the Icelandic geysers, he poured pure water into a glass tube two meters long and blackened on the inside. He was able to detect a faint blue under these circumstances and concluded that water is actually blue. The other colors besides blue must then be due to foreign substances or to the reflection of light from a colored background. Bunsen did not go into details as to the way in which the color changes would occur. Some twenty years later, Tyndall put forward the view that the blue color of the sky is due to the scattering of light from numberless, colorless particles suspended in the air. This suggested to Soret [7] that the blue color of the Lake of Geneva might be due to similar causes and he found that the water sends out light polarized perpendicularly to the refracted rays of the sun. The analogy between the experiments of Tyndall and of Soret is so close that one may claim the existence in the water of transparent particles which may be the cause of the color. Hagenbach [8] repeated these experiments at the Lake of Lucerne, getting similar results. The following year, Tyndall [9] himself examined water from the Mediterranean and from the Lake of Geneva, sent to him in London. When a beam of light was passed through them, it became blue and the blue light was polarized. These waters are therefore not optically empty. These experiments seem to show conclusively that the water itself is colorless, contrary to the opinion of Bunsen; but this is not necessarily true. Soret himself points out that on cloudy days there was not a trace of polarization and yet the lake was blue. This is sufficient to prove that reflection is not the sole cause of the color of the water. Further, if the blue of the water were due to exactly the same

* Communicated by the Author.

† Concluded from page 271, Vol. 187, March, 1919.

[7] *Ann. Chim. Phys.* (4) **17**, 517 (1869).

[8] *Ann. Chim. Phys.* (4) **20**, 225 (1870).

[9] *Naturforscher*, **4**, 1 (1871).

cause as the blue of the sky, the light transmitted by the water should be a crimson red at least as intense as that which lights up the tops of the high mountains or the thin clouds through which pass the rays of the rising and setting sun. This is not the case, however, as Tyndall himself points out. Also Father Secchi [10] has determined the absorption spectrum of sea-water and finds that the red and yellow are lacking. It is also well known to people who have been down in a diving-bell or who have visited the Swiss grottoes cut in the ice of the Rhone or the Grindelwald glacier that the light is bluish. There is so little red that faces appear livid.

"In 1848 H. Sainte-Claire Deville [11] analyzed a large number of natural waters and he observed that the blue waters of the Swiss and the Jura lakes, when evaporated, leave residues which are only slightly colored, while the green waters of the Doubs and the Rhine, contain a considerable amount of organic matter, so that the soluble salts were colored distinctly yellow when the water was evaporated. From this it appears that the green waters and still more the yellow or brown ones may owe their color to the presence of a small amount of yellow mud. If pure water is really blue, a small amount of yellow coloring would be sufficient to change the color to green or even to yellow. This same idea crops up again in a much later paper on the color of water by Wittstein.[12] This chemist analyzed the waters of many of the brooks, rivers and lakes of Bavaria, and thought that he had proved that the brown or yellow waters contain more organic matter and are less hard than the green waters. He explains the different shades of natural waters by assuming, with Bunsen, that pure water has a blue color, that the mineral substances dissolved in the water have no effect on the color, and that the different colors are due chiefly to dissolved organic matter. These organic substances are brown in color and are essentially humic acids. They are kept in solution by the presence in the water of a sufficient amount of alkali salts. On this hypothesis a water containing very little organic matter would be practically blue, while the blue color would change continuously to green, yellow, brown and black, as the amount of organic matter increased.

[10] *Naturforscher*, **1**, 149 (1868).
[11] *Ann. Chim. Phys.* (3) **23**, 32 (1848).
[12] Vierteljahresschrift für praktische Pharmacie, **10**, 342 (1861).

"It is worth while to examine this hypothesis. At first sight it seems an excellent one because it rests apparently on definite facts; but it is easy to show that the hypothesis does not follow necessarily from the analytical data. It is therefore without any firm foundation and does not solve the question. I shall not stop to discuss the question whether the organic matter is brown when it is in solution or whether it becomes brown and even black during the evaporation. In view of the description of the evaporation given by Wittstein, it seems probable that the deep color is due to the action of heat.[13] Such a discussion would be a waste of time. Let us rather consider the analytical data as shown in Tables II and III.

TABLE II.
Brown waters (p.p.m.).

	Organic Matter.	KOH and NaOH.	Ratio.
Ily	37.8	10.1	3.74
Regensee	21.4	15.4	1.39
Rachelsee	43.3	18.4	2.35
Ohe	111.4	12.8	9.0
Steckenbach	55.0	9.5	3.68
Hohenbrunnfilz	59.7	7.8	6.50

TABLE III.
Bluish-green waters (p.p.m.).

	Organic Matter.	KOH and NaOH.	Ratio.
Isaar	39.6	9.8	4.04
Brunnthaler Spring	65.6	4.7	13.97

"These figures show that the color of the waters stands in no direct relation, either to the amount of organic matter or to the alkali concentration. The green Isaar contains more organic matter than four of the brown waters and also more alkali than two of them. The waters from the Brunnthaler spring show similar relations. It is also worth noticing that Wittstein gives no analysis of a really blue water and consequently there is no

[13] During the evaporation insoluble brown flocks form and become even darker. If heat changes the solubility of the organic matter, it may also affect the color.

real basis for a comparison. He also makes the general rule that greenish-blue waters are hard because of the small amounts of alkali which they contain while the yellow or brown waters are soft, and then he admits that the rule holds only for running water because the waters of the Lake of Starnberg are extraordinarily soft although green. I add that the blue waters of the Rhone, where the river flows out of the Lake of Geneva, are also soft, as is shown by the large number of laundries along the river. It is evident that the color is not different for running and for stationary waters. Wittstein's hypothesis therefore seems insufficient. It may be true, however, for some very deeply-colored waters because if these really hold a colored material in solution or in suspension, their color ought to be dark.

"Schleinitz [14] attributes the change in the color of sea-water to the greater or lesser amount of dissolved salts. He noticed sudden changes in the color of the sea when he was crossing from Ascension towards the Congo on board the *Gazelle* in 1875. On August 23, 5° south latitude and 9° west longitude, the sea changed from blue to greenish. On the twenty-fifth it was bluish and on the twenty-sixth in 5.5° south latitude and 5.5° west longitude, the sea became again deep green, changing to a dirty green and then to a brown as the ship approached the Congo. Later, on the voyage from the Congo to the Cape, the sea became green, then bluish-green, and finally bright blue. Each time that the sea became greenish Schleinitz found that its specific gravity decreased while there was an increase when the sea became blue again. From this he concluded that the bluest water contained the most salt and that the salt was the cause of the color. Although this observation led to a false conclusion, it confirms some of the results which I have found and I shall come back to it again.

"It is worth noting that in the waters of the Lake of Neufchatel and also in the ice from the lake, J. Brun [15] found an alga which is green, orange, red, or brown, depending on the different phases of its development, and turns black after death. Its presence might well affect the color of the water."

In order to determine the color of pure water Spring took two tubes five metres long and about four centimetres inside diameter, coated with black on the outside. When distilled water

[14] *Naturforscher*, **8**, 59 (1875).
[15] Jahresbericht über Chemie, **1880**, 1512.

from the laboratory supply was put into the tubes, the color was a light green very like that of a dilute ferrous sulphate solution. Some days later the tubes were filled with freshly-distilled water and the color was a fairly pure sky-blue. After standing about seventy hours in the tubes this water was as green as the first without having lost anything of its clearness. This preliminary experiment shows that the distilled water of the laboratory is far from being pure and contains substances which undergo changes, in that a blue water becomes green slowly. These foreign substances may be inorganic or organic; it is not impossible that they are living organisms. The following experiment is evidence in favor of this. "The two tubes were filled with distilled water but one ten-thousandth of mercuric chloride was added to one tube. At first both tubes were blue and there was no perceptible difference between them. After six days the water in one tube had become green, while the water containing the mercuric chloride had not changed in color, and even after three weeks the blue color was the same. Mercuric chloride was then added to the green tube and after three days a distinct change towards blue was noticeable. At the end of nine days no further change took place and the water was distinctly bluish-green; but it never returned to a pure blue. Since mercuric chloride is one of the most toxic substances known, especially for minute organisms, there is certainly reason to believe that living organisms are to be found in the distilled water of the laboratory and that the water also contains the food necessary for the development of these organisms. . . .

"Stas[16] has shown that rain water or spring water, if distilled twice, gives a liquid which volatilizes without leaving any residue if evaporated at once in a platinum vessel. If this same distilled water is kept several days and then evaporated, it leaves a noticeable brownish-yellow residue, which burns completely at red heat in the air. Stas concluded that distilled water contains volatile organic matter which becomes non-volatile spontaneously in the course of a few days. This conclusion fits in well with my observations. So long as the distilled water contains the dissolved organic matter in a volatile state, the water is blue by transmitted light, but it becomes more and more green as the dissolved matter becomes changed by the action of organisms and ceases to be

[16] Bull. Acad. roy. belg. (2) 10, (1860).

volatile. A similar fact has also been observed by P. Glan [17] in his studies on the absorption of light. He calls attention to the difficulties due to the presence of foreign matter which it is almost impossible to remove. He notes that after distilled water has stood several days in a closed vessel, it lets less light through and appears as though turbid.

"These preliminary experiments show that the distilled water of the laboratory is absolutely unfit for experiments like these, for it changes on standing. Stas [18] has pointed out a method for obtaining pure distilled water. It consists in distilling spring water with a mixture of manganate and permanganate of potash, taking care to condense the vapor in a platinum cooler. Water prepared by this method contains no trace of non-volatile organic matter either when first distilled or later. I have made use of this method, taking all sorts of precautions. Ordinary water was first boiled with alkaline permanganate for four hours in a glass vessel. It was then distilled twice in an apparatus made entirely of platinum and was collected in a closed silver flask out of contact with the air. In order to clean the apparatus, three litres of water were distilled and thrown away. Then the first fifth of the final amount of water distilled was used to wash the surface of the silver flask. I have satisfied myself that water thus prepared is volatile without residue. To show this I have polished the inside of a platinum crucible with precipitated and dried silica so as to get a brilliant surface on which the least trace of residue would show. When the water was evaporated in this closed crucible, no visible deposit could be detected on the mirror surface, and I believe that one cannot say that such water contains any non-volatile material.

"When this pure water was poured into the tubes it is hard to describe the purity of the blue color which was seen. The only thing that could be compared to it is the most beautiful blue of the sky on a clear day at the top of a high mountain when one is far above the mists rising from the ground. When the tubes were allowed to stand for two weeks, no change in the purity of the blue could be detected. This permanence of color is perhaps a proof of the extreme purity of the water. I have tested this water by the Tyndall method, focussing a magnesium

[17] Pogg. Ann. **141**, 66 (1870).
[18] Mém. Acad. roy. belg. **35**, 110 (1865).

flame on one point in the tube by means of a concave mirror. Unless my imperfect apparatus has led me into error, the luminous cone was scarcely visible in the liquid. It was difficult for me to say whether its path could be detected or not. Whatever one may think on this point, it appears certain that the purest water which one can prepare is a wonderful blue if one looks through a sufficiently thick layer. Is this color peculiar to the water or is it due to a reflection of the incident light as is the case with the blue of the sky? I think that everybody will reject any hypothesis as to the color being fortuitous. Under the conditions as arranged, one looked through the water along the axis of the tubes in the direction of the illuminating ray. If the blue were due to the reflection of light from otherwise invisible particles, the maximum intensity of the blue color should be found in a direction perpendicular to the luminous ray, which is just the opposite to what occurs actually. Further, on this assumption the transmitted light ought to be red or mixed with red, which is not the case, the purity of the blue proving the absence of red. In addition I have made another experiment which seems to me conclusive. If the blue color of water is not characteristic of this substance and if it is due to the presence of foreign matter coming from the air, it follows that any liquid would be blue like the water if treated in the same way. In other words, there could be no colorless liquid. I have distilled five litres of amyl alcohol for several weeks in a glass vessel and exposed to the air of the laboratory. In spite of this careless treatment and in spite of the fact that the liquid had taken up a good deal of dust, there was no sign of color in the tube when the layer was five metres in thickness. Lack of material prevented an examination of a layer ten metres in thickness.

"At first I tried crystallized acetic acid and absolute ethyl alcohol, but these substances were yellow when examined in a five-metre layer. This yellow color disappeared gradually as the layer was made thinner without showing either green or blue. I am not certain, however, that these substances are really yellow because acetic acid and ethyl alcohol are apt to contain empyreumatic substances which are very difficult to remove. It seems certain from these experiments that the purest water one can prepare is not colorless but has a blue color due to an absorption in the yellow and not to a reflection of the incident light.

"We can now discuss the causes of the different colors of

natural waters. Since analysis has not shown in any definite way the presence of green, yellow or brown matter in the green waters, and since Wittstein himself admitted the absence of any yellow mud in the green water of the Lake of Starnberg, a different line of attack must be chosen. Five litres of pure, blue water were treated with a few grams of a lime containing no iron and obtained by calcining Carrara marble. This lime water was quite clear after standing for five days. A solution of carbon dioxide in water was added until a precipitate was just barely visible. When placed in the tubes the water was then absolutely opaque. It would not have been any different if ink had been poured into the tube instead of this calcareous water. The water was taken out of the tube, diluted with pure water, and treated with carbon dioxide to precipitate the calcium carbonate and then to redissolve it as bicarbonate. Every now and then the current of carbonic acid gas was cut off and the water was examined in the tubes. The original opacity disappeared slowly and the light which came through was first brown, then pale brown, yellow, green, and finally the liquid became blue again though with a touch of green after the carbonic acid had been run in for eighteen hours. With the combined action of carbon dioxide and calcium carbonate it is thus possible to reproduce all the colors of natural waters from complete opacity to a greenish-blue.

"As a further confirmation I have prepared a saturated solution of calcium carbonate and carbon dioxide in pure water, which was green when viewed through a five-metre layer. I then placed this in a vacuum to draw off some of the carbon dioxide and to cause a dissociation of the bicarbonate, after which the liquid was examined in the tube. Each time this was done, the color became more yellow. The green disappeared soon and finally the tube became opaque. A drop of hydrochloric acid brought back the greenish-blue color. Similar results were obtained with barium hydroxide and carbon dioxide. With excess of the latter the water became brown, yellow, green and bluish-green. Using hydrochloric or nitric acid instead of carbon doixide the color changes are obtained more rapidly. A solution of sodium silicate containing a little free silicic acid was opaque in a five-metre layer and brownish-yellow when a metre in thickness. When a concentrated solution of caustic soda was added to dissolve the free silicic acid, the yellow color disappeared. Pure water holding

in suspension a little amorphous silver chloride is opaque or yellow, depending on the thickness of the layer. Ammonia dissolves the precipitate and removes the opacity or the yellow color.

"These experiments warrant the drawing of several conclusions. A luminous beam of given intensity will not pass through a sufficiently thick layer of a liquid holding enough particles in suspension even though these are transparent or colorless. A tube containing suspended calcium carbonate, barium carbonate, silica or silver chloride may be opaque to diffused daylight and yet let through light from the sun or from burning magnesium. The physical state of the suspended particles does not affect the phenomenon. If one pours water into ethyl alcohol containing a little dissolved amyl alcohol, a persistent turbidity is caused, due to the minute drops of amyl alcohol which do not dissolve in the water. By varying the amounts of ethyl alcohol and water for a given amount of amyl alcohol, one can change the degree of turbidity and make it as small as one pleases. It is evident that each drop of amyl alcohol is liquid and transparent, and yet such a turbid liquid is opaque for a definite thickness of layer and intensity of light; it is yellow if the light is more intense and colorless under a very powerful light. Similar changes take place if the intensity of the light is kept constant and the thickness of the layer decreases. The reason for this is easy to see. When a ray of white light passes through a medium which holds in suspension an infinity of reflectors, each simple wave forming the white light is reflected independently of the others. If there is not total reflection the intensity of each wave will decrease with increasing thickness of the layer. Since the different colors constituting white light have not the same luminous intensity, the weakest will disappear first and the color at the ends of the spectrum, the red and the violet, will be eliminated early while the yellow, which is the most intense to our eyes, will outlast the others though weakened itself. One could probably explain the phenomenon in another way and say that when white light passes through an absorbing medium the yellow is the last to disappear.

"I will add that it is not necessary to have a liquid holding reflecting particles in suspension. A similar phenomenon occurs in the air. Everybody has noticed that the shadow projected by smoke or by condensing vapor on a white background is not merely gray; it always has a yellow-brown color to which one

gives the name of yellow smoke or brown smoke. A liquid holding a colorless substance in suspension appears white solely because of the reflected light. Milky lime water, though very white, is as opaque as ink, and the white color shows merely that the light which illuminates it does not pass through it.

"There is still another point which calls for attention. If the yellow color of a liquid is due to the suspension of a certain number of solid or liquid particles, the color should disappear as the particles sink; it should be ephemeral. If this were true, the suggested explanation of the different colors of natural waters would present a real difficulty; but this is not the case. I have allowed a turbid lime-water solution to stand for seventeen days in the observation tubes. At first no light came through, but after some time the lime began to precipitate in the tube and the liquid became more and more green. At the end of twelve days the water was so clear that one could see through the tube a light pencil mark on a piece of paper. The color of the water was green, nevertheless, and remained so. It was evident that I was dealing with a solution of lime in water without any real suspension of solid matter, and yet there was enough yellow left to form a green with the blue of the water. Turbid waters containing bicarbonate of calcium or of barium in suspension show the same phenomenon, whence it follows that the resistance to the passage of light manifests itself also when light passes through saturated solutions where a precipitate is ready to form. This last might be called a nascent precipitate by analogy with the nascent clouds which Tyndall has taught us to recognize. To test this point experimentally, I have made at 18° a nearly saturated solution of pure calcium chloride containing no iron. In the observation tube this solution was a beautiful greenish-yellow. When diluted with water or when the thickness of the layer was decreased, the green became more marked. An almost saturated solution of pure magnesium chloride has shown a very pure golden yellow. A saturated solution of equally pure sodium chloride was wonderfully transparent and had a magnificent chrome-green color. I have not examined solutions of other salts because of the difficulty of getting them really free from iron. I believe nevertheless that it is proved that the yellow color produced by dissolving a salt depends less on the amount of salt dissolved than on the nearness of the solution to the crystallization point. Small amounts of a slightly soluble

salt will produce the same effect as large amounts of a more soluble substance. To test this directly, I boiled pure, blue, distilled water for some time in a glass flask. It is known that glass is slightly soluble in water. When the cooled water was poured into the observation tube, it proved to be completely opaque. After some hours a deep yellow light passed and at the end of two days it became green and remained so. Its clearness was then very great, but the small amount of transparent material which had been taken from the glass was enough to color it green.

"We can now show how the observed facts may be used to account for the colors of natural waters. We start with the assumption that a sufficiently thick layer of absolutely pure water has a beautiful blue color. If small amounts of colorless salts are in true solution, the color of the water will remain blue; but if the water contains greater or lesser amounts of a nascent precipitate the light passing through the water will be a more or less deep yellow. There may even come a point at which no light will pass and the liquid will appear opaque; in other words, black. The yellow light will necessarily blend with the blue of the water to form a series of tints which will vary with the amount of yellow from greenish-blue through bluish-green to green. If there is too much yellow, the blue will disappear and the water will be a brown-yellow or even darker.

"Let us see now how these conditions may be realized in nature. The sparingly soluble substances in the natural waters, which may appear as nascent precipitates, are for the most part calcium carbonate, magnesium carbonate, silica, aluminum silicate or alumina. It is not necessary to consider the more soluble substances such as the chlorides and sulphates of sodium and magnesium because they do not occur in sufficient quantities to produce the effects in question. A blue water like the Lake of Geneva, or, better, like the Lake of Achen in the Tyrol, must have the calcareous matter more completely dissolved the more blue the water is. There must therefore be a sufficient amount of carbon dioxide to form calcium bicarbonate. A green water, on the other hand, like that of the Lake of Constance, must have the calcareous matter in a less perfect state of solution, which must be due to there being relatively less carbon dioxide in the water. It is interesting to note that these predictions are verified. In 1848 Sainte-Claire Deville analyzed the green water of the

Rhine at Strassburg and the blue waters of the Rhone at Geneva, determining also the dissolved carbon dioxide.[19] The data which interest us are given in Table IV. When referred to a constant quantity of calcium carbonate there is relatively nearly twice as much carbonic dioxide in the waters of the Rhone as in those of the Rhine. The calcareous matter is therefore dissolved more completely in the former case and, as a matter of fact, the waters of the Rhone are blue.

"If it is true that, when other things are equal, a calcareous water is more blue the more completely the calcareous matter is dissolved, it ought to be possible to make a blue water green by bringing it in contact with lime-stone. The free carbon dioxide would then be converted completely into calcium bicarbonate. In the Lake of Achen the water is a deep blue out in the lake and a most beautiful chrome-green along the northern shore where the

TABLE IV.
(*p. p. m.*).

	Rhine.	Rhone.
Calcium carbonate	135.6	78.9
Free carbon dioxide	7.6	7.95

water is shallow and the bottom consists of lime-stone pebbles from which the waves grind off invisible particles of calcium carbonate, thus causing a change of color. The greenish tones of shoals at sea and along the edges of lakes are probably due to the same thing. The sands of the sea contain fragments of crushed shells and the lands along the shores of the lakes are usually sufficiently calcareous to saturate part of the carbon dioxide in the water.

"So far we have considered only the calcareous matter; but silica and alumina can produce the same effect. A green water might contain no trace of calcareous matter, in which case the silica or alumina would have to produce the color. Would a water containing alumina and silica give different tints and would it be possible to remove the alumina in any simple and

[19] It is surprising that these two analyses are the only ones given in the chemical literature. Are there no others?

natural way? The answer to this is easy. We know that clay or aluminum silicate forms a pseudo-solution in water though not soluble in the true sense of the word. The water of a river flowing over a fat, clayey mud, does not become completely clear on standing. Although the clay is not dissolved, it acts as though emulsified in the liquid. If one adds to the water a solution of a salt, such as sodium chloride, the aluminum silicate precipitates rapidly. This may be observed on an enormous scale at the mouths of large rivers. Their waters remain turbid even though the current has almost disappeared, so long as they do not mix with the sea-water. When this happens, the mud settles rapidly and this accounts for the formation of those deltas which are built up grain by grain and yet finally dam the river which formed them and force it to change its course. When the alumina precipitates the water becomes blue again. Reference has been made to the observations of Schleinitz on board the *Gazelle* as to the sudden changes in the color of the sea. He noticed that there was an increase in the density of the water when the blue color reappeared and he therefore concluded that the blue color was due to the salt. The real explanation is that the salt precipitates the aluminum silicate, which had caused the green color, when present in suspension in the water.

"One other point may be raised. Is it not possible that the polarization of the light observed by Hagenbach and by Soret in the Swiss lakes was due to the reflections which produce the yellow color rather than to reflections producing the blue color?"

While denying that suspended particles are the cause of the blue color of water, Spring [20] recognizes the important part which they play in the color phenomena.

"One might think that the blue color of water would be sufficient in itself to account for the blue color of the Atlantic, the Mediterranean, and certain lakes; but this is not so. The action of water on the different components of white light varies very much. It absorbs the red strongly even in thin layers but it absorbs the other colors to some extent. If one were to examine the solar spectrum after sunlight has passed through an ever-increasing thickness of pure water, one would find the red, the orange, the yellow and the green disappearing successively and finally the blue when the thickness of the layer was sufficient. The light

[20] Bull. Acad. roy. belg. (3) 12, 814 (1886).

of the sun would therefore be absorbed completely in absolutely pure water if the water were deep enough. Such water would therefore appear as black as ink. Can such a depth of water be realized in nature? Some years ago Fol and Sarasin[21] made some new experiments to complete work begun by Fol and others, in which they showed that daylight does not penetrate more than two hundred metres into the waters of the Lake of Geneva even in calm weather and in the month of August. They proved this by lowering to different depths in the lake a special apparatus containing photographic dry plates with a rapid bromide emulsion made by our countryman Van Monckhoven. Those plates which were lowered 237–300 metres showed no effect of light when developed, whereas at 170 metres the illumination was apparently about equivalent to that on a clear but moonless night.

"Depths of more than two hundred metres are the rule not only in the ocean but also in most lakes. Consequently these deep waters, from which the light should never return, ought to appear absolutely black to us. Their surface might send back some reflected rays just as ink will; but the mass of the liquid ought not to appear colored if it sends back no light. Along the shores and in the shallows the blue color might show because the conditions would be more or less favorable for the daylight being reflected to the eye. The real phenomenon is quite different. The deepest waters are the bluest and in the shallow waters the blue gives way to green or even to yellowish-green and brown. How are we to account for this? . . .

"Tyndall has shown that no natural water is optically empty. Even after standing a long time the water of the Mediterranean and that of the Lake of Geneva scatters a beam of light. We therefore see the natural blue of certain seas and certain lakes because the daylight does not penetrate far enough into them to be absorbed completely. It encounters myriads of particles of foreign substances which reflect it in all directions like a multitude of microscopic mirrors. The effect to the observer is the same as though he were looking through a very thick layer. From this it follows that in a very deep and very clear lake containing relatively few suspended particles, a beam of light would penetrate further than into a more turbid water before all the rays would be reflected back. This clearer water would be a deeper blue and

[21] Comptes rendus, 100, 991 (1885).

we find actually that the dark blue waters emit less light. It is also easy to explain the variations in the quality and intensity of these waters with sky changes or with varying agitation of the surface. . . .

"If the suspended particles are relatively numerous, a beam of incident light will not be reflected often in the water before melting the particle which will send it out. The blue will therefore not be saturated and will contain much white light. If the particles are few and far between, the beam will pass through a longer route in the water and the effect will be the same as though the observer were looking through a greater thickness. The blue will be more saturated and a deeper shade. In consequence of these multiple reflections the apparent illumination of the water does not necessarily come from a very great depth. The phenomenon is like that observed by all tourists in the mountains who have crossed freshly-fallen fields of snow consisting of the original small crystals which have not yet agglomerated to larger grains. Each hole made by sinking the point of the ice-axe in this snow is illuminated by the most beautiful blue light. This blue does not come from the depths of the ice or the snow but is due to the fact that a ray of white light has been reflected a million times more or less from the surfaces of the little snow crystals before reaching the eye of the tourist. At each one of these reflections from a blue substance it has lost some of the reddish light and consequently appears more and more blue. This explains why the waters of some mountain torrents are a beautiful blue, the intensity of which seems out of proportion to the depth of the water. The Ticino gives a series of illustrations of this between Airolo and Bellinzona. This explains why a light object, like an oar for instance, appears blue when plunged a little way into the water of a blue lake, even though the layer of water covering it is not itself sufficient to show the blue. The light reflected back by the object has not only traversed the slight depth between it and the surface, but comes also by reflection from the sides and is therefore blue.

"If the lateral distances are not sufficient, as is often the case near the shores of a lake or a sea, the phenomenon becomes complicated. The light coming from these points will necessarily be less saturated with blue even though the bottom is white. Since water absorbs most readily the least refrangible or red rays, and

then the others less and less completely up to the blue rays, the less refrangible rays will not be cut off in a thin layer of water and the light will appear green. This is probably the reason that the waves of the blue sea appear green. One really sees them by light transmitted through a relatively thin layer."

In a later paper Spring [22] points out that an optically empty water may appear blue when seen from above if the temperature of the liquid is not homogeneous. A column of water unequally heated is equivalent to a light fog if the tube is short and to a dense black cloud if the tube is long enough. "The light is reflected and refracted from the layers of unequal density and is scattered irregularly in all directions as though the liquid contained infinitely small particles. In other words, such a medium does not behave like an optically empty one. This is important for the illumination of clear natural waters. A lake of pure water will appear blue if there are convection currents in it. The presence of solid particles is not absolutely necessary. If the convection currents are infrequent the lake will appear much darker, even though there has been no change in the chemical composition of the water. This is true experimentally. Forel [23] points out that the soft-water lakes are more transparent in winter than in summer. This is because in summer there is a greater difference between the temperatures at the surface and in the depths. In consequence of agitation due to many causes, the layers of water of different density do not remain stratified one above the other in a regular manner. They mix and convection currents are produced in all sorts of directions scattering the light every which way. Forel has observed that during the summer months it is absolutely impossible to see the bottom and to detect the ancient objects which one looks for in the ruins of the lacustrine cities at depths of 3–6 metres. In the winter the water is usually transparent enough to make the search profitable."

Special experiments showed that in a tube twenty-six metres long a difference of 0.57° between the water in the tube and the surrounding medium is enough to produce opacity. "This slight difference is quite within the order of temperature variations which must occur inevitably in the waters of lakes and seas. It makes us see that the tint cannot be the same in the zones exposed

[22] Bull. Acad. roy. belg. (3) **31**, 94, 256 (1896).
[23] Arch. Sci. phys. nat. **59** (1877).

to the sun's rays and in the zones situated in the shadow of a cloud or a mountain. The water which receives the rays of the sun must appear more luminous not merely because of the greater amount of light which falls upon it but also because the solar energy makes the water less transparent than that in the shade. If the wind blows unevenly over the surface of the water, differences of the same order may be noted. The wind causes evaporation which lowers the temperature of the water, thus neutralizing the convection currents due to the heating by the sun's rays, and making the water appear more transparent, or less illuminated. This accounts for the difference in tints to be noticed on the surface of lakes and seas, differences which indicate to some extent the direction of the wind."

TABLE V.

Fe_2O_3	Color.
1 : 10 000	Dark mahogany brown
1 : 100 000	Deep yellow
1 : 1 ½ 000 000	Yellow
1 : 2 000 000	Golden yellow
1 : 4 ½ 000 000	Yellow with trace of green
1 : 6 000 000	More yellow than green
1 : 8 000 000	Grass green
1 : 10 000 000	Green with trace of blue
1 : 12 000 000	Bluish-green
1 : 18 000 000	Greenish-blue
1 : 20 000 000	Blue with trace of green
1 : 24 000 000	Blue like pure water

In still another paper Spring[24] takes up the question of colored compounds in the water, especially iron and humus. He determined the color of pure water containing varying amounts of ferric oxide in solution or suspension. He did this by dissolving in aqua regia 0.700 g. iron which is equivalent to 1 g. of Fe_2O_3. After this had been evaporated to dryness on the water-bath, the product was dissolved in one litre of pure water distilled in a platinum apparatus. This yellow-brown solution was then diluted and examined after dilution in a tube five metres long. The data are given in Table V.

"From this it follows that ferric oxide affects the blue color so soon as its concentration gets above one part in twenty-four

[24] Bull. Acad. roy. belg. (3) 31 578 (1897).

millions. On the other hand, the Lake of Geneva contains one part of ferric oxide in about three million, but the water is blue and not yellow. The water of the Meuse is green and not yellow when it contains one part of ferric oxide in 1,500,000 of water. On the basis of analysis the Mediterranean should be brownish-yellow and not blue. From this it follows that the iron in these waters is not present in the same state as when a solution is made up in the laboratory. The point that has been overlooked is the effect of humic matter. . . .

"In order to get suitable humic matter I have taken the black waters from the peat bog on the plateau of Baraque Michel, which is the highest plateau in Belgium. In this way I was certain of getting water uncontaminated by industrial products and containing only the brown-black compounds dissolved from the peat. It is therefore probable that the substances used corresponded closely and perhaps absolutely with the humic matter found in so-called pure, natural waters. In fact the water I used was black as ink by reflected light but somewhat coffee-brown by transmitted light when observed in a twenty-centimetre layer. It can be filtered through filter paper, though very slowly, which proves that the brown substance is not entirely in solution. Its density was 0.99885 at 25.5°. Since pure water has a density of 0.99759 the peat water was 1.0012 times as dense. When examined with a spectroscope it gave a continuous, dark spectrum, in which one saw only red and green, but no blue and almost no yellow. It had a slight acid reaction. When evaporated in a platinum crucible, it left a black residue of 0.152 g. per litre. After the carbonaceous matter had been destroyed by heating in the air the residue weighed 0.0238 g. There were therefore 0.1282 g. of organic combustible matter per litre of water. The small content of mineral matter (0.0238 g./litre) indicated a water that has not flowed far through the earth. It is actually rain-water filtered slowly through a layer of peat.

"With this peat water the effect of humic matter on the color of water has been determined. The data are given in Table VI, the concentrations being grams of combustible matter per gram of water.

"This table shows the extreme coloring power of humic matter. It has an effect about double that of ferric oxide if one compares equal weights. It is therefore easy to see the difficulties

to be surmounted in a laboratory preparation of a really blue water, a pure water not containing more than one part in fifty million of organic matter.

"Filtered water from the Meuse contains about one gram of combustible matter in nine thousand of water. If the combustible matter in the water of the Meuse were brown, soluble, humic material like that of the peat water, the river should look like a river of ink. The organic matter of the natural waters can no more be dissolved humic matter than the ferric compounds can be in a true state of solution. The concentration is more than a thousand times that which corresponds to the actual color of the water.

TABLE VI.

Humic Matter.	Color.
1 : 500 000	Yellow-brown
1 : 1 000 000	Yellow
1 : 10 000 000	Yellowish-green
1 : 20 000 000	Green
1 : 30 000 000	Bluish-green
1 : 40 000 000	Greenish-blue
1 : 50 000 000	Blue

"From the preceding results one might expect to get a very dark brown liquid by mixing water containing a ferric salt with water containing humic material; but this is not the case. The water clears up and the rate of clearing is faster the more intense the light. . . . Under the influence of light the organic matter reduces the ferric salts to some extent, converting them into green ferrous compounds, the coloring effect of which is not comparable with that of the ferric compounds. Owing to the absorbed oxygen the humic matter probably becomes more acid and therefore forms salts more readily with the oxides of iron, alumina, etc., these [hypothetical] salts precipitating readily on account of their insolubility. The ferrous compounds remaining in solution are oxidied by the action of the air or by the oxygen dissolved in the water. When converted into ferric compounds they oxidize more of the unprecipitated organic matter. The ferric compounds therefore act in natural waters in the way hæmoglobin does in the blood of animals. . . . Hæmoglobin is looked upon as

an oxygen carrier, taking it up from the lungs and distributing it through the system. The organic substances in the water are immersed in a medium which burns them while the body of an animal is irrigated by an oxidizing liquid.

"The interaction of ferric salts and organic substances under the influence of light gives rise to an apparent equilibrium between the oxygen of the air and the ferrous compounds. If the intensity of the light increases, the proportion of ferric compounds decreases, because the organic substances will be oxidized more completely. Since the water will then contain smaller amounts of yellow or brown compounds, it will become more and more distinctly blue. On the other hand if the intensity of the light decreases, the rate of the oxidation will decrease and the water will become more and more green, or even yellow, because the supply of coloring matter will not fall off with decreasing intensity of light. It is therefore easy to see why waters exposed to the sun are usually the bluest.

"If the amount of iron is very small relatively to that of the humic substances, these latter may be oxidized very slowly, in which case they will impart their brown, or even black, tint to the waters in which they are. The black waters of the equatorial regions of South America are said [25] to contain 0.028 grams of *free humic acids* per litre, a little more than one-fifth as much as the *black* peat water from the plateau of Baraque Michel in Belgium. In his paper on the color of water, Wittstein [26] has pointed out that the brown waters of Bavaria are remarkable for their softness. They contain almost no mineral matter.

"If the amount of iron is relatively large, there may be almost complete elimination of the organic matter. Almen [27] has called attention to the purity of the great lakes of Sweden. Lake Wettern is almost free from organic matter. Between these extremes there are the more common cases where the waters contain iron and organic substances in what one may call ordinary amounts. If one omits the instances where these waters are obviously turbid, their color will be a dark green like those of most of our rivers, the Meuse, for instance, the waters of which are

[25] Muntz and Marcano: Comptes rendus, **107**, 231 (1888).
[26] Vierteljahresschrift prakt. Pharmacie, **10**, 346 (1861).
[27] Ber. deutsch. chem. Ges. **4**, 750 (1871).

characterized by the absence of depth of color and by a lack of that transparency which one finds in lakes or in the ocean. This is the effect that would be produced by the joint presence of iron and of organic substances.

"In so far as the waters of the river are exposed to the sunlight, a purification is continually taking place. If the river is sufficiently long, the purification may even be complete before the waters reach the sea. This happens with the Nile. The upper waters are green in the dry season and become more and more blue as one approaches the mouth of the river. In this case one can exclude the hypothesis of the change of color being due to the influx of other waters. It is the water of the Nile itself which changes color as it flows to the sea.

"In this way one can account for the deep blue color of the high seas and in general of large masses of water, even when the analysis does not permit us to recognize any important differences. The ease with which humic matters combine with ferric oxide makes it clear why ferruginous mineral deposits always contain organic matter. In fact, the limonites of the prairies and the ochres have been suggested as raw material for making humic compounds."

The green often observed in swimming pools is undoubtedly due to suspended matter, though I can find no record of anybody having determined the exact nature of the suspended matter.

A special point has been discussed by Steuer.[28] "The color and the transparency of the water of the Danube bear so close a relation one to the other that we cannot treat them separately. We may draw the following general conclusions: In winter the water is usually turbid and green to yellowish-green; the melting snow and ice in the spring with the consequent rise of level, together with the influence of the drainage water, increase the turbidity and make the color of the river even more yellow. That the color of the Danube never is blue except in the song, is well known. At best the water is greenish and usually it is a dirty yellow. On the other hand, after a few windless days in late autumn, winter and occasionally in spring, the water of the 'old Danube' becomes quite clear and appears a beautiful blue. Apart from the presence of plankton, the transparency and change of color of

[28] Zoologische Jahrbücher, Abth. für Systematik, Geographie und Biologie der Thiere 15, 7 (1902).

the water vary with the suspended particles of sand or mud which are removed from the shore or the low islands by strong winds or high waves; are carried in by drainage water from the ground and also from the right bank; or are brought down by the melting snows in the spring."

The work of Aitken and Spring would seem to have settled the whole question were it not that Lord Rayleigh[29] has recently brought the matter up again. "A recent voyage around Africa recalled my attention to interesting problems connected with the color of the sea. They are not always easy of solution in consequence of the circumstance that there are several possible sources of color whose action would be much in the same direction. We must bear in mind that the absorption, or proper, color of water cannot manifest itself unless the light traverse a sufficient thickness before reaching the eye. In the ocean the depth is of course adequate to develop the color, but if the water is clear there is often nothing to send the light back to the observer. Under these circumstances the proper color cannot be seen. The much admired dark blue of the deep sea has nothing to do with the color of water, but is simply the blue of the sky seen by reflection. When the heavens are overcast the water looks gray and leaden; and even when the clouding is partial, the sea appears gray under the clouds, though elsewhere it may show color. It is remarkable that a fact so easy of observation is unknown to many even of those who have written from a scientific point of view. One circumstance which may raise doubts is that the blue of the deep sea often looks purer and fuller than that of the sky. I think the explanation is that we are apt to make comparison with that part of the sky which lies near the horizon, whereas the best blue comes from near the zenith. In fact, when the water is smooth and the angle of observation such as to reflect the low sky, the apparent blue of the water is much deteriorated. Under these circumstances a rippling due to wind greatly enhances the color by reflecting light from higher up. Seen from the deck of a steamer, those parts of the waves which slope towards the observer show the best color for a like reason.

"The real color of ocean water may often be seen when there are breakers. Light, perhaps directly from the sun, may then traverse the crest of the waves and afterwards reach the observer.

[29] *Nature*, **83**, 48 (1910); Scientific Papers, **5**, 540 (1912).

In my experience such light shows decidedly green. Again, over the screw of the ship a good deal of air is entangled and carried down, thus providing the necessary reflection from under the surface. Here also the color is green.

"The only places where I have seen the sea look blue in a manner not explicable by reflection of the sky were Aden and Suez. Although the sky was not absolutely overcast, it seemed that part at any rate of the copious, if not very deep, blue was to be attributed to the water. This requires not only that the proper color of the water should here be blue, but also the presence of suspended matter capable of returning the light, unless indeed the sea bottom itself could serve the purpose.

"The famous grotto at Capri gives an unusually good opportunity of seeing the true color of the water. Doubtless a great part of the effect is due to the eye being shielded from external glare and so better capable of appreciating the comparatively feeble light which has traversed considerable thicknesses of water. The question was successfully discussed many years ago by Melloni, who remarks that the beauty of the color varies a good deal with the weather. The light which can penetrate comes from the sky and not directly from the sun. When the day is clear, the blueness of the sky coöperates with the blueness of the water.

"That light reflected from the surface of a liquid does not exhibit the absorption color is exemplified by brown peaty water such as is often met with in Scotland. The sky seen by reflection is as blue as if the water were pure. But an attempt to illustrate this fact by experiment upon quite a small scale was not at first successful. A large white photographic dish containing dark brown oxidized 'pyro' was exposed upon the lawn during a fine day. Although the reflected light certainly came from the clear sky, the color did not appear pronounced, partly in consequence of the glare of the sunshine from the edges of the dish. The substitution of a dish of glass effected an improvement. But it was when the eye was protected from extraneous light by the hands, or more perfectly by the interposition of a pasteboard tube held close up, that the blue of the reflected light manifested its proper purity. It would seem that the explanation is to be sought in diffusion of light within the lens of the eye in consequence of which, especially in elderly persons, the whole field is liable to be suffused with any strong light finding access.

"As regards the proper color of pure water, an early opinion is that of Davy, who, in his *Salmonia,* pronounces in favor of blue, basing his conclusion upon observations of snow and glacier streams. The latter, indeed, are often turbid, but deposit the ground-up rock which they contain when opportunity offers, as in the Lake of Geneva. A like conclusion was later put forward by Bunsen on the basis of laboratory observations. The most elaborate experiments are those of Spring, who, in a series of papers published during many years, discusses the difficult questions involved. He tried columns of great length—up to 26 metres; but even when the distance traversed was only 4 or 5 metres, he finds the color a fine blue only to be compared with the purest sky-blue as seen from a great elevation. But when the tubes contain ordinary water, even ordinary distilled water, the color is green, or yellow-green, and not blue.

"The conversion of the original blue into green is, of course, explicable if there be the slightest contamination with coloring matter of a yellow character—*i.e.,* strongly absorbent of blue light. Spring shows that this is the effect of minute traces—down to one ten-millionth part—of iron in the ferric state, or of humus. The greenness of many natural waters is thus easily understood. Another question examined by Spring is not without bearing upon our present subject—viz., the presence of suspended matter. I am the better able to appreciate the work of Spring, that many years ago I tried a variety of methods, including distillation *in vacuo,* in order to obtain water in the condition which Tyndall described as 'optically empty,' but I met with no success. Spring has shown that the desired result may be obtained by the formation within the body of the liquid of a gelatinous precipitate of alumina or oxide of iron, by which the fine particles of suspended matter are ultimately carried down.

"Perhaps the most telling observations upon the color of water are those of Count Aufsess, who measured the actual transmission of light belonging to various parts of the spectrum. The principal absorption is in the red and yellow. In the case of the purest water there was practically no absorption above the line F, and a high degree of transparency in this region was attained even by some natural waters. That these waters should show blue, when *in sufficient thickness,* is a necessary consequence.

"In my own experiments, made before I was acquainted with

the work of Aufsess, the light traversed two glass tubes of an aggregate length of about 4 metres (12 feet). On occasion the light was reflected back so as to traverse this length twice over. I must confess that I have never seen a blue answering to Spring's description, when the original light was white. For final test I was careful to employ the light of a completely overcast day, which was reflected into the tubes by a small mirror. The color, after transmission, showed itself very sensitive to the character of the original source. The palest clear sky of an English winter's day gave a greatly enhanced blue, while, on the other hand, isolated clouds are usually yellowish, and influence the result in the opposite direction. I should myself describe the best color of the transmitted light on standard days as a greenish blue, but there is some variation in the use of words, and, perhaps, in vision. Some of my friends, but not the majority, spoke of blue simply, but all were agreed that the blueness of a good sky was not approached. The waters tried have been very various. Sea-water from outside the grotto of Capri, from Suez and from near the Seven Stones Lightship off the Cornish coast, I owe to the kindness of friends. Of these the two former showed a greenish-blue, the latter a full, or perhaps rather yellowish, green, and these colors were not appreciably modified after the water had stood in the tubes for weeks. It is important to remember that the hue may to some extent depend upon the thickness. It is quite probable that in a greatly increased thickness the Capri and Suez waters would assume a more decided blue color. But I do not think the Seven Stones water could so behave, the color, with 12 feet, seeming to involve the absorption of blue light. Further observations on greater depths of sea-water would be desirable. A naval son informs me that off the coast of Greece a plate lying in 6 fathoms of water looked decidedly blue, although the sky was a dirty gray. I have doubts whether this would be generally the case in the Mediterranean; the green due to moderate thicknesses seems too decided.

"Of natural fresh waters that I have tried, none were better than that from a spring in my own garden. This water is hard, but bright and clear, and it shows a greenish-blue, barely distinguishable from that of the Capri and Suez water. Distillation does not improve the blue. Neither did other treatments do any good, such, for example, as partial precipitation of the lime with

alkali, or passage of ozone with the idea of oxidizing humus. Wishing to try water of high chemical purity, I obtained—through the kind offices of Sir J. Dewar—water twice distilled from alkaline permanganate, and condensed in contact with silver, but the color was no bluer. In the light of this evidence I can hardly avoid the conclusion that the blueness of water in length of 4 metres has been exaggerated, especially by Spring, although I have no reason to doubt that a fully developed blue may be obtained at much greater thicknesses. I should suppose that sufficient care has not been taken to start with white light. It may be recalled that overcast days are not so common in some parts of the world as in England.

"A third possible cause of apparent blueness of the sea must also be mentioned. If a liquid is not absolutely clear, but contains in suspension very minute particles, it will disperse light of a blue character. Although, undoubtedly, this cause must operate to some extent, I have seen no reason to think that it is important. But the existence of three possible causes of blueness complicates the interpretation of the phenomena. Hitherto, observers have not been sufficiently upon their guard to distinguish blueness having its origin in the sky from blueness fairly attributable to the water itself."

The question at issue seems to be whether Lord Rayleigh's negative results are to outweigh Spring's positive results. On general principles, there are so many ways of failing in an experiment that a positive result usually outweighs any number of negative ones. On the other hand, Lord Rayleigh is such a careful worker that his conclusions are not to be rejected hastily. The fact that he does not give details to the same extent that Spring does cannot be charged against him because he was delivering an address before the Royal Institution while Spring was writing a series of scientific papers. The whole question must therefore be considered as open for the present though one may at least hope that Spring will prove to be right.

Beebe [30] seems to feel that the color of water is entirely an optical illusion. "One finds numerous examples of these sensory deceits at sea. The wind flutters the fins of the flying fish and we think they actually fly. The tropic sea, under the palest of green skies, is saturated ultramarine, save where the propellers churn it

[30] "Sea-Wrack." *Atlantic Monthly*, 1918, 481.

to pea-green, yet in our bath the water is clear and colorless. . . . The great unlovely bow rose and reached forward and settled, until, as I lay face-downward our speed seemed increased manyfold. And I wondered if the wooden expression which always marked the figure-head ladies and gods had not its origin in the hypnotic joy of forever watching the molten cobalt crash into alabaster, this into emerald, then to merge again into the blue, which is a hue born of depth and space and not of pigment."

CORNELL UNIVERSITY.

Researches on Fog-Signal Sound Measurement. L. V. KING. (*The Honorary Advisory Council for Scientific and Industrial Research*, Dominion of Canada, Bulletin No. 2, Ottawa, 1918.)—Canada has been among the most progressive of maritime countries in the experimental development of fog-alarm systems. The type of fog-alarm which has found favor in Canadian waters, and has been installed in many localities, is a modified form of compressed-air siren, known as the "diaphone." The original diaphone was invented by Dr. Owen Hope-Jones. Its utilization for fog-alarm purposes was first suggested by Lieut-Col. Anderson, Chief Engineer of Department of Marine and Fisheries of Canada, who with his chief assistant, Mr. B. H. Frazer, determined from numerous tests the lines along which the diaphone evolved into full-sized fog-signal apparatus in the hands of Mr. J. P. Marthey of Toronto.

Although powerful sirens have been in use in all maritime countries for nearly half a century, there was until recently comparatively little accurate information available regarding the way in which sound waves were actually generated in such apparatus. It has long been known that existing types of sirens or steam whistles are extremely inefficient; that is, little of the power furnished is converted into sound of such a character or quality as will penetrate a desired distance in foggy weather. The extent to which it is possible to protect a trade route in this way from accidents due to fog depends ultimately on the power, penetration and reliability of the fog-alarms which can be installed and operated at a given cost. The difficulty in the development of what may be called "acoustic engineering" has been the almost total lack of sound-measuring instruments. The development of fog-signalling machinery has also been retarded by the fact that experimental tests are not only very costly but have had to be conducted at isolated stations far removed from laboratory facilities.

From the work of Lord Rayleigh, Webster and others, it was known that the proportion of power converted into sound with musical instruments was exceedingly small, in many cases less than one part in a thousand. It was found that the sound from a diaphone unprovided with a trumpet was extremely complex, and that the effect of a trumpet of correct design was to concen-

trate a greater proportion of the power into the master tone. During propagation through the atmosphere, the overtones do not travel far but are filtered out, the master tone surviving to an appreciable extent at distances greater than two miles. It is now possible to state in horse power or watts the total acoustical output of a siren as well as to compute the relative proportion of power expended in the master tone and overtones. That this may be done as a test is of great importance, as the designer will now be able to predetermine the behavior of fog-signal apparatus without having the equipment installed at great expense at some station by the sea. It is to be expected that with the methods of carrying out the required tests available, the development and improvement of sirens will be much more rapid than in the past.

Chemical Warfare—A New Weapon. E. HENDRICK. (*Chemical and Metallurgical Engineering,* vol. xx, No. 4, p. 152, February 15, 1919.)—The opinion seems to prevail generally that the use of poison gas, launched in breach of faith by the German high command, has reached an end for all time; that by general agreement in convention it will no longer be endured, and that it will be classed with the many practices of violence and debauchery of which the Germany army was guilty. This is not in accord with the opinion of Brigadier-General Amos A. Fries of the U. S. Engineers, who was in command of the chemical warfare service of our army in action. The allied troops used chemical warfare in constantly increasing measure because it is an effective weapon. On the other hand atrocities were neither encouraged, practiced or permitted. It is General Fries' belief that the use of other chemicals besides shot and shell, having been introduced into the art of war, can never be eliminated. The situation is somewhat like that when gunpowder was introduced, and universally frowned upon as unfair and unsportsmanlike; yet it has endured.

While conventions may agree to forbid the practice of chemical warfare, it is a remarkable weapon of offense. Its employment places an army at so great an advantage over an unprepared enemy that it will be difficult to trust nations to forego its use. It is exceedingly inviting for police work, because it may be made effective without involving fatal casualties or maiming. The question, therefore, must be met whether future wars shall be controlled or not. If they are to be fought under international supervision, under rules akin to an international code duello—in which event it would seem that swords alone should be the proper weapon—then we have every reason to hope for the best, so long as the supervisors do not get to fighting among themselves. On the other hand, it may be that scientific warfare will be recognized, and allowed to develop until war itself shall be prohibited by some working agreement, owing to its destruction of the world's accumulated property. Half way measures and compromises do not meet the situation. If there is to be an international police, the chemical munitions will be needed to avoid unnecessary loss of life.

INSTITUTES OF APPLIED SCIENCE.*

BY

P. G. NUTTING, Ph.D.,

Engineer in charge of Research Laboratory, Westinghouse Electric and Manufacturing Company.

THE future of any nation depends in large measure upon the degree to which fundamental principles are developed and applied to the solution of its national economic and industrial problems great and small. And as between our need of knowledge and our need of experts to apply that knowledge, it is difficult to say which is greater. Our supply of either is woefully inadequate and likely to continue so under our present system of research institutions. The remedy for this condition here proposed may possibly prove to be a solution of the problem.

Experts are produced and our store of knowledge is increased by the working out of individual concrete problems, and by no other means. This statement is almost a platitude and is accepted generally by all thinking men. But the national problem of the most efficient means of obtaining the best results has apparently been given little consideration. Research institutions we have, of high quality and in considerable numbers, but none of them are well adapted to fill our national need. By way of illustration, let us first consider the results obtained by each of the seven or eight distinct types of existing research institutions and the extent to which they meet the requirements of the nation.

A research institution to be efficient in turning out experts and vital fundamental principles should possess the following qualifications:

1. The breadth of the field covered should not be too wide nor too narrow—preferably such as may be adequately covered by a staff of not less than twenty nor more than one hundred men. Lists of typical fields of intensive research are given farther on in this article.

2. The director and the leader in each of the five to ten subfields should be the recognized leaders in their fields.

3. Close contact with corresponding industries should be maintained through suitable location and selection of research problems.

* Communicated by the Author.

4. There should be maintained the closest coöperation and team work between members of the staff, with free and full discussion of plans and results. Given the proper organization and a director generous with ideas and advice and tactful in handling men, this matter presents few difficulties.

5. With the possible exception of a few leaders, members of the staff should be free to enter and leave the institution as they see fit. An annual turnover of from 10 to 30 per cent. of the staff is perhaps the most advantageous.

6. There should be no domination over research by untechnical men, and the least possible by the leading members of the staff.

7. Freedom to publish results, undertake outside work and otherwise profit by his work should be recognized in every member of the staff.

Each of the existing types of research organizations falls short of meeting the requirements just mentioned in at least one item. The seven principal types in this country are as follows:

University Research.—This is excellent for the teaching of fundamental principles in both the principal and in related subjects and also in regard to freedom of choice of work, but it is essentially preparatory in the process of making experts. Aside from some work by a few instructors, there is little continuity to the work, and therefore large problems as a rule are not attempted. There is practically no team work between men working on the same group of problems. There is also little or no direct contact with technical work and practical industrial problems, and therefore very little incentive from without.

Government Research.—The characteristics of research in the best government bureaus are intermediate between those of the university and industrial types. The tendency is to be too academic, due partly to heavy recruiting of the staff directly from universities and partly to defective contact with the more important technical problems. Excellent work in biological research is done in various bureaus, but even these are by no means well adapted to turning out well and broadly trained experts.

Industrial Research, General Type.—In the best-organized industrial research laboratories the field covered is appropriate. Team work and coöperation are highly developed. There is ample incentive to development and just the proper amount of

contact with technical work. From the national standpoint, the expansion of these means inefficient duplication of work, and they are never regarded as schools for turning out experts for the benefit of the public. Conditions 1 to 4, described above, are fulfilled very closely, whereas in regard to 5, 6 and 7, they fall wide of the mark.

Industrial Research, Piece-Work Type.—Such laboratories as the Mellon Institute are in close contact with technical problems and men are free to come and go. There is, however, almost no team work and very little coöperation nor continuity of effort. Working on individual isolated jobs is not an efficient means of developing broad groups of fundamental principles, and the experts turned out by this type of laboratory are seldom men of broad training and experience.

Private Consulting Research.—The few private consulting research laboratories of the type of A. D. Little, Inc., are in close contact with important technical problems and team work is well developed. Their defect is in covering too broad a field and in doing too little intensive work of a general character. They are fitted to turn out practical money-making experts, but not to advance any applied science in general.

Coöperative Testing and Research.—There are a few efficient laboratories doing important testing and research which are purely coöperative organizations, such as the Electrical Testing Laboratories of New York. Very little fundamental research is attempted and very few experts of broad training are turned out. However, both this and the preceding type demonstrate that research laboratories may be made self-supporting.

Foundation Research.—Such special research laboratories as have been fostered by the Carnegie Institution are well adapted to developing experts as well as increasing our knowledge of fundamental principles. The Geophysical Laboratory, the Magnetic Laboratory and the Mount Wilson Observatory are ideal in their freedom from financial domination, and are splendidly adapted to take care of neglected fields of research. It is, however, unnecessary and probably undesirable to provide such endowed laboratories throughout the field of industry, while the industries chiefly benefited are so well able to finance them.

In passing, it may be well to cite other proposed methods of research having precisely the objectives outlined in our introduc-

tion. Of large national grants of money for wholesale research not much is to be expected, since it is unlikely that conditions 1 to 5, above, will be fulfilled. If, however, such research were subdivided into suitable organizations, each intelligently directed, there would be little to criticize in the scheme. Again, massive bodies of eminent scientists are unlikely to be productive, however ably assisted. Here again, if subdivided into suitable groups, such bodies of scientists might well exercise a beneficent influence on such institutions as are proposed. State controlled institutes of research might be organized to operate efficiently, but more or less obstructive political or academic control would be anticipated.

The Research Institute.—The proposed new form of research institution would take men from the universities, already thoroughly grounded in the known fundamental principles relating to their chosen lines, and provide them with ample facilities (salary included) for actual vital research along those lines, each in company with a score or hundred other men working along more or less closely related lines. Our best industrial research laboratories have demonstrated that this is a very efficient means of developing experts. Our universities are unfitted for indefinitely holding large bodies of investigators, for they either cannot pay them reasonable salaries or else require the major portion of their time for teaching. Further, but few universities are well provided with productive research problems for their advanced students.

While industrial research laboratories may produce great experts in a minimum of time, the future of these experts is tied up with the concern to which they are attached. Any valuable results obtained are, of course, the property of the company. In the proposed form of research institution each individual would be more or less arbiter of his own destiny, free to come and go and dispose of himself or the results of his labors more or less as he sees fit. It is planned to have every member of these institutes quite free to accept calls for consulting work from anyone, anywhere at any time. Since private consulting research laboratories, so inefficiently organized (since covering too broad a field and with the staff not necessarily made up of the highest grade experts), can show a cash balance, it seems more than likely that a carefully organized body of men, greater in number and working more intensively in a narrower field, would pay even better.

What it is planned to establish is a series of Institutes of Applied Science in each of about thirty fields of applied science, each consisting of from twenty to one hundred men, covering intensively a rather narrow field and each engaged on the type of research characteristic of the best industrial research laboratories. It would probably be best to have such institutions incorporated and under the nominal directorship of one of our scientific or engineering societies. Capital would be required to start such an institute, but if incorporated it would be in an excellent position to finance itself eventually when fully staffed with experts. A moderate salary should be paid, with the expectation that it would be supplemented with consulting fees. The less remunerative research would be attractive to some who would hope thereby to obtain a reputation of cash value. For persons of independent means wishing to do research for its own sake, no better opportunity could be offered anywhere than in such an institute.

In order to illustrate the point of proper depth of field a list is given below of fields for research adapted for being covered in individual research institutes. Some of these might well perhaps be subdivided. Others might be initially treated in groups and subdivided later. In most cases the most advantageous location or locations are obvious. For example, an institute devoted to problems in ferrous metallurgy might well be located in Pittsburgh, an institute of ceramics in either New Jersey, Ohio or Illinois, applied optics in Rochester, rubber products in Ohio, etc. In some lines—for example, in agriculture—it would appear advisable to have from five to ten institutes of a kind, even at the risk of considerable duplication in the research work done. The agricultural experiment stations at various state universities under government subsidy are doing excellent work as a rule, but many of these would be improved by being remodeled and expanded.

INSTITUTES OF RESEARCH IN APPLIED SCIENCE.

Agriculture:
- Agronomy
- Animal Husbandry
- Dairying and Dairy Products
- Fruit and Fruit Products
- Soils and Fertilizers

Applied Optics
Astronomic Research
Atmospheric and Solar Research
Building Materials
Ceramic Products
Dyes and Dye Products
Electrochemical Processes
Explosives

Fats, Oils and Waxes
Fisheries and Fish Products
Food and Food Products
Forestry and Forest Products
Fuel and Fuel Products
Geodetic Research
Geophysical Research
Leathers, Glue and Gelatine
Medical Research on:
  Cancer
  Contagious Diseases
  General Bacteriology
  Surgery
  Tuberculosis
Metallurgy:
  Ferrous
  Non-Ferrous
  Rare Metals
Paints, Oils and Varnishes
Paper and Cellulose Products
Petroleum and Petroleum Products
Pharmacy and Physiological Chemistry
Public Health and Sanitation
Radio Communication
Roads and Road Materials
Rubber and Rubber Products
Starch and Starch Products

Such institutes would cost on the average perhaps $120,000 for the plant and equipment, and say $60,000 per year for operating expenses. The director and say six section heads should receive a direct salary of from four to six thousand. Twenty or thirty of the more experienced men should receive salaries ranging from one to four thousand. Fellowships paying say six hundred should be offered all worthy applicants to the limit of accommodations. Ten to sixty per cent. of consulting fees might well be turned over to the institute. Likewise, firms sending their own men to the institute for special research should contribute a percentage for the privilege. In time almost any well-managed research institute should become self-supporting. The initiative might well be taken by a group of consulting specialists, groups of related industries or by the national government itself. The chief dangers to be avoided are in attempting to cover a field too broad to permit of intensive research and in non-scientific domination. They should in every case be under the nominal control of one of our scientific or technical societies.

For the sake of comparison, lists are given below of schools for special instruction in which the primary object is to develop experts rather than to advance knowledge. These fall naturally into two classes, the engineering and the civic types. Such schools of special instruction may well be and in fact are, fairly well taken care of by our better universities and technological institutes. Instruction is chiefly through testing and research, but of such a nature that it does not involve much team work nor application over a period of years. Along these lines the future expert may step directly from the university into field work.

INSTITUTES OF EXPERT INSTRUCTION.

Engineering Type.	*Civic Type.*
Aeronautic Engineering	Appraising and Accounting
Automotive Engineering	Banking and Finance
Building Construction	Charities and Corrections
Electrical Construction and Operation	Civic Administration
Forestry	Commerce and Trade
Heating and Ventilating Engineering	Communication
Illuminating Engineering	Education
Inland Waterway Engineering	Efficiency and Cost Engineering
Irrigation Engineering	Employment
Medicine, Dentistry, Surgery	Fisheries and Game
Meteorological Engineering	Insurance
Military Science	Journalism and Information
Mining Engineering	Law: Corporation
National Defense	Criminal
Naval Construction	International
Navigation	Patent
Railway Engineering	Marketing and Buying
Road Construction	Penology
Sanitary Engineering	Recreation and Physical Training
Surveying and Geodesy	Statistics
Telephone and Telegraph Construction and Operation	Taxes and Tariffs
Water Power Engineering	Transportation

The time is ripe for professional research on a large scale. We have been experimenting with research methods long enough. The wide gap between the university and the real expert must be closed. Let dilettantism in research by amateurs be displaced by the concentrated efforts of strong men working in coördination toward definite ends. Our national welfare demands it and we are well prepared. We are committed to the sensible plan of developing expert knowledge and applying it to all our practical problems. Let us also apply this principle to research itself.

PITTSBURGH, PA.,
January, 1919.

The Next Step in Applied Science. G. T. W. PATRICK. (*The Scientific Monthly*, vol. viii, No. 2, p. 118, February, 1919.)—It was long ago that Plato taught that science should not be applied to the mechanical and industrial arts, but to education, social culture and social health. A century and a half have passed since Rousseau's celebrated essay, in which he tried to show that the arts and sciences had done nothing to advance human happiness. From our modern viewpoint, these were the pathetic mistakes of great men, so richly, as we think, has science vindicated itself in its practical application. While we may not question the almost unlimited possibilities in the application of science to social welfare, nevertheless we may raise the question whether science has thus far been applied to the right things. We may not, indeed, question the potential value of applied science, nor even its actual value in countless directions. What we may question is whether there has been a mistaken conception to the general end to which science should be applied in respect to real social welfare.

Applied science has surrounded us with comforts, conveniences and luxuries of every kind; but just what will be the effect upon a race of men, disciplined through a hundred thousand years of hardships, of this sudden introduction to comfort? Possibly science should never have been applied to making man comfortable, but to making him perfect. It may be that there is great danger in comfort. The biologist holds it in grave suspicion; degeneracy is its sequel. Another of the most brilliant triumphs of applied science is seen in our countless and wonderful labor-saving devices. We simply assume that increased wealth and decreased labor are human blessings, although both may be quite the opposite. It has been seriously questioned whether civilized man has gained enough moral and physical poise to be trusted with the immense wealth which applied science, working upon our suddenly acquired store of coal and iron, has supplied. Then there are the time-saving devices. It is, no doubt, because of the temper of the day that so few have questioned their intrinsic value. But with all these time-saving devices, it is not quite apparent that we have any more time than formerly. Even if there results a certain amount of leisure, much depends upon the manner in which the leisure is spent.

Science has always been applied, and successfully, to our immediate needs as they were understood. The immediate needs of our present time are not more wealth and more luxury and more efficiency, but more social and constitutional power of resistance to physical disease, and more individual power of resistance to every alluring immediate joy which threatens the permanent welfare of society. We need steadiness and self-control and the limitation of our desires. The centrifugal motive which has ruled the world for the last fifty years has gone far enough. The world is small and there are limits to the expansive opportunities both of the nation and the individual.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ELECTRICAL CHARACTERISTICS AND TESTING OF DRY CELLS.[1]

By G. W. Vinal and H. D. Holler.

[ABSTRACT.]

THIS circular summarizes the available information on dry cells. A brief description of the materials and methods of construction, and elementary theory of the operation of the cells is given. The various sizes and kinds of dry cells on the American market are described. The electrical characteristics of the cells and methods of testing them are discussed. In an appendix are given the proposed specifications for dry cells which have been prepared by the Bureau.

OPTICAL CONDITIONS ACCOMPANYING THE STRIÆ WHICH APPEAR AS IMPERFECTIONS IN OPTICAL GLASS.[2]

By Lt. Commander A. A. Michelson.

[ABSTRACT.]

STRIÆ are conveniently divided into two classes; 1st, those which appear as isolated bright streaks; 2nd, those in which such streaks are numerous, forming bright irregularly continuous bands. Optical investigation with two forms of interferometers shows that the former are due to laminæ of smaller index and of thickness of the order of a hundredth of a mm. They do not seriously affect the optical qualities of lenses or prisms. The second class of striæ in general does not affect the optical performance; but, in the case of lenses and plane parallel plates, etc., in which the light traverses the striæ at approximately normal incidence, the performance may be quite as good as with a perfect specimen.

* Communicated by the Director.

[1] Circular 79.

[2] Scientific Paper No. 333.

CONSERVATION OF TIN IN BEARING METALS, BRONZES, AND SOLDERS.[1]

By G. K. Burgess and R. W. Woodward.

[ABSTRACT.]

THIS paper gives practical suggestions for the conservation of tin in bearing metals, bronzes, and solders; much of the data having been obtained from questionaires sent to representative manufacturers and users of the above named alloys. Tables are given showing the chemical composition and physical properties of many of the suggested alloys and also for service tests of genuine babbitt and a high lead bearing metal. Tentative recommendations for standard grades of bearing metal are also included.

Proper solders for various industrial uses are recommended and a new solder consisting of a preponderance of lead with small amounts of tin and cadmium is desired.

Selenium for Red Glass. ANON. (*American Chemical Society News Service Bulletin No. 223,* February, 1919.)—Engine drivers and motormen who fail to distinguish the hues of colored lights may not always be growing color-blind. According to Mr. H. E. Howe, of the American Chemical Society, tests show that not only the eyes must be perfect in their color perception, but that the utmost care must be taken by the chemist in choosing the material for coloring glass.

Red as a danger signal and green for a clear track are firmly established in railroading. A veteran engine driver who was suspected of failing vision properly identified a red light at close view, but at a considerable distance pronounced it green. The man's color perception was growing weak, particularly so far as red was concerned. The red glass of the lantern permitted some green rays to pass and while all eyes would not have perceived them, others with peculiar characteristics would have done so. The red discs employed were made of copper ruby glass. Glass that is unquestionably red owes its true transmission of red rays to the presence of a waste material, a by-product of copper refining for which chemistry had been seeking a use—selenium. If selenium ruby glass be compared with other ruby glass by means of the spectroscope, those colors toward the blue end of the spectrum fail to pass, while various wavelengths are transmitted through other less reliable vitreous material.

[1] Technological Paper No. 109.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

EXAMINATION OF ORGANIC DEVELOPING AGENTS.[1]

By H. T. Clarke.

[ABSTRACT.]

THE commoner developing agents are classified into four main groups, based upon their solubility in water, ether, and alcohol. Group I, insoluble in water, comprises p-Hydroxyphenylglycine; Group II, soluble in ether, includes Hydroquinone, Chlorhydroquinone, Catechol, and Pyrogallol; Group III, soluble in alcohol, consists of p-Aminophenol and its hydrochloride, 5-Amino-2 hydroxytoluene hydrochloride, 2-4 Diaminophenol hydrochloride, p-Dimethylaminophenol oxalate; Group IIIa, insoluble in alcohol. consists of p-Aminophenol sulphate, 5-Amino-2-hydroxytoluene sulphate, p-Methylaminophenol sulphate, p-Dimethylaminophenol sulphate, o-Methylaminophenol sulphate, and p-Phenylenediamine hydrochloride.

The different members of these groups are partly distinguishable by their behavior on treatment with sodium carbonate, ferric chloride, and silver nitrate solutions.

The salient properties of each substance are described, and the melting points of characteristic derivatives, such as those produced by acetylation and benzoylation, are recorded.

A few methods for the quantitative examination of developing agents are indicated, and several typical analyses of genuine and spurious products are quoted.

* Communicated by the Director.

[1] Communication No. 73 from the Research Laboratory of the Eastman Kodak Company, published in *Jour. Ind. & Eng. Chem.*, vol. 10, p. 891, November, 1918.

Solders for Aluminum. ANON. (*Circular of the Bureau of Standards*, No. 78, January 28, 1919.)—The question is frequently raised in connection with the use of aluminum and its alloys whether they can be satisfactorily soldered, and if so, by what method and with what metals or alloys. Aluminum, and to a greater extent its alloys, can be welded quite satisfactorily by the oxygen-gas process, but often it is not desirable to heat the parts to be joined to the relatively high temperature necessary to weld them in this manner, owing to the resultant distortion of the parts, and a means of joining at lower temperatures is sought. In response to the general interest in the utilization of this method, evidenced by the inquiries which are received, the Bureau has gathered data on the subject, based upon current experience, and made special tests which are here summarized:

All metals or combinations of metals used for aluminum soldering are electrolytically electronegative to aluminum. A soldered joint is therefore rapidly attacked when exposed to moisture and disintegrated. There is no solder for aluminum of which this is not true. Joints should accordingly never be made by soldering unless they are to be protected against corrosion by a paint or varnish, or unless they are quite heavy, such as repairs in castings, when corrosion and disintegration of the joint near the exposed surface would be of little consequence.

The surfaces to be soldered are carefully cleaned with a file or with emery, and are then "tinned" or coated with a layer of the solder by heating the surface and rubbing the solder into it. Solders are best applied without a flux. The composition of the solder may be varied within wide limits. It should consist of a tin base with addition of zinc or both zinc and aluminum, the chief function of which is to produce a semifluid mixture within the range of soldering temperatures. Tin-zinc solders may range from 15 to 50 per cent. of zinc, with the remainder tin. Tin-zinc-aluminum solders may have a varying composition of zinc, 8 to 15 per cent.; aluminum, 5 to 12 per cent.; and the remainder tin.

The higher the temperature at which the "tinning" is done, the better the adhesion of the tinned layer. By using the higher values of the recommended zinc and aluminum percentages given, the solder will be too stiff at lower temperature to solder readily, and the workman will be obliged to use a higher temperature which secures a better joint. A perfect union between solder and aluminum is very difficult to obtain. The joint between previously tinned surfaces may be made by ordinary methods and with ordinary soft solder. Only the tinning mixture need be special for aluminum. There is no reason why a good solder for aluminum need be brittle, as several commercial varieties are, and it is very undesirable that it should be. The tensile strength of a good aluminum solder is about 7000 pounds per square inch. The strength of a joint depends upon the type and upon the workmanship. Much dependence should not be placed upon the strength of a joint.

NOTES FROM THE PHYSICAL LABORATORY OF THE UNITED GAS IMPROVEMENT COMPANY.*

A PRECISION PRESSURE GAUGE.

By Edward J. Brady.

THIS note is a brief description of a precision pressure gauge of high sensibility and great accuracy recently constructed at this Laboratory.

In principle it is virtually a large diameter U tube (6 cm. diam.) filled with some transparent nonvolatile, nonoxidizing liquid such as kerosene or paraffin oil. In each leg is placed a hollow brass float. The two floats are connected together with a fine silk thread which passes downward around a light graduated wheel with jewel bearings immersed in oil at the bottom. The position of the wheel, which is provided with a vernier, is read through a glass window in one end of the box that forms the bottom of the gauge.

Laboratory workers having to do with the accurate measurement of small gas pressure, either plus or minus, are greatly in need of an instrument similiar to the one to be described.

The way in which the differential pressure enters in the formulæ for both the Venturi meter and the Pitot tube may be represented by $P=(f)\ Q^2$ where P is the pressure that must be read and Q is the quantity of material passed. It will be seen that both of the methods become increasingly inaccurate at low velocity, because of the difficulty of measuring small pressures accurately. This gauge ought to increase the usefulness of both the Venturi and the Pitot tube.

A modification of the gauge with an opening to receive the horizontal velocity pressure of the wind might be used as an anemometer.

The two glass cylinders are cemented into the removable cover of a brass box, one end of which has a glass window. To the lower side of the cover is fastened the little yoke supporting the two jewel bearings in which the index wheel or drum revolves. To one arm of this yoke is fastened a projecting piece carrying a

* Communicated by the Manager.

vernier flush with the graduated surface of the wheel. There is a small groove on the face of the wheel around which passes the silk thread that holds the two hollow floats almost totally immersed in the fluid. Any pressure P on this liquid in one tube produces a linear motion at the circumference of the wheel of $\frac{P}{2}$.

The diameter of the wheel was so chosen that a pressure of one inch of distilled water exerted on a parrafin oil, such as kerosene, produces a motion of the periphery of the wheel of 10 divisions. By the aid of the vernier this precision can be increased.

These cylinders are made of glass so that the gauge can be read approximately and from a distance like an ordinary U gauge with the inch mark on the scale between the two cylinders.

Its use as a zero reading instrument capable of indicating pressure differences of less than 10^{-3} inches of water, will now be described.

Upon the little shaft that carries the graduated wheel there is fastened a small mirror, arranged to face toward the glass window in the lower position. About 4 feet in front of the gauge there is mounted a telescope and scale. This can only be used for comparatively small variations in pressure, say less than 2/10". However, the telescope and scale may be used to measure small differences at pressures of, say, 2"–3" and 4", by moving the mirror around on the shaft, so that it has the proper aspect when the gauge is subjected to the above pressures.

This is facilitated by a small bent movable wire, projecting through a stuffing box in the side. It is pushed in sufficiently to interfere with the rotation of the mirror until the float assumes the position corresponding with the pressure whose small variation is to be measured. It is then withdrawn, when the telescope and scale can be used as before.

The glass window may be made a section of a cylinder, so that all rays from the scale would pass normally through the glass, eliminating refraction effects, but this was not found necessary in practice.

The instrument as constructed has twin hollow brass floats and a brass wheel below. The bearings are jewelled, with very little friction. The friction may easily be made as near zero as is possible by making the wheel of aluminum and so proportioning it that the weight of the wheel *in the oil used* is just equal to the buoyancy of the two floats.

Even with the brass wheel having some weight on the bearings, the system has a very definite zero. The motion of the mirror for small displacements is almost critically damped.

The instrument may be dismantled by inserting two small wire hooks through the hose connections at the top to support the floats while the oil flows out at the bottom.

A gauge constructed as above described has been in use at this laboratory and has given entire satisfaction. When not in use a small piece of rubber tubing is connected from one inlet to the other to keep the dust out. With an ordinary U gauge an accumulation of dirt invariably appears at the point where the menisci are read; with this gauge, however, the graduations on both the wheel and the vernier are immersed in the oil and always appear bright and clean.

A SPECIFIC GRAVITY APPARATUS FOR GASES.

By E. J. Brady.

THE simplest method of determining the specific gravity of gas would be by means of a U tube with liquid in the lower end, similar to the method used for determining the density of liquids. This method has not been used for gases, because of the extremely small differential pressure that would have to be measured to obtain accuracy. The pressure gauge in the preceding note makes the use of this method possible.

The apparatus devised consisted of a tall tube, through which the gas was passed, having its lower end connected with the precision gauge by means of a four-way cock. At the upper end there is a pilot flame, if the gases being measured are inflammable. The gases being measured passed through this vertical tube, which is opened to the air through a suitable burner at the top. A quarter turn of the cock cuts off the gas and connects this column of gas with the precision pressure gauge, which will immediately indicate a slight suction produced on the gauge, provided that the gas is lighter than the air. This cock may be turned a number of times to obtain check readings on the same sample of gas. Using the telescope and scale as described, we may graduate the scale to read in specific gravity direct. The gravity as shown by a tube of this kind would, of course, include any foreign matter, such as particles of dust or vapors. But, inasmuch as these

materials assist in producing the differential pressure in the Pitot tube or the Venturi meter, they should be taken into consideration in applying the formula for these instruments.

Gases heavier than air, such as oxygen, carbon dioxide, etc., may also be measured, the deflection produced being in the opposite direction.

For more accurate work, where the absolute density of the gas is wanted, we might provide a vertical tube for air also. This air could be dried to eliminate the effect of moisture and the whole system surrounded by the constant temperature bath.

Where the density of hot gases relative to air are required, the vertical air pipe could be carried *within* the vertical gas pipe, so that the air would quickly assume the same temperature as the gas being measured. In many places a vertical tube of much greater height would be permissible. In this case the telescope and scale could be dispensed with and the differential pressure read from the Vernier direct.

Remarkable Pitting of Electro-plating. O. P. WATTS. (*Proceedings of the American Electrochemical Society*, April 3-5, 1919.)—When making some lead platings, heavy pitting suddenly and irregularly appeared. After considerable study of the cause, it was finally found to be due to air dissolving in the electrolyte while it was resting over night and cooling, which was then expelled as minute air bubbles on the work when the bath was heated up by the passage of the current. The microscopic bubbles clinging to the work, which had been left immersed in the bath, started the pitting. (J. W. R.) The difficulty was overcome by heating the solution to a little above its working temperature by means of a lead steam coil before resuming plating, whenever the tanks had been out of use for any considerable time.

Similar trouble by gas-pitting may be expected whenever a plating solution that is used for heavy deposits, and operates at an elevated temperature, stands idle and cold for many hours; but if there is a steady evolution of hydrogen from the cathode during normal operation of the bath, as with the cyanide copper or the brass solution, no trouble need be anticipated, for the stream of gas, ascending along the surface of the metal, will prevent bubbles from clinging long enough to form pits in the plating. Pitting may be expected only when the rate of evolution of gas from the work is extremely slow.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

MUTAROTATION OF GELATIN AND ITS SIGNIFICANCE IN GELATION.[1]

By C. R. Smith.

[ABSTRACT.]

GELATIN at and above 35° C. has a constant specific rotation of −123°. Between 35° and 15° C. higher values are obtained which vary with concentration. Below 15° C. the specific rotation reaches a maximum and constant value of −268°. The increase in levorotation is progressive with time, and requires about 16 hours for completion.

These results point to the existence of two forms—Sol Form A, stable above 35° C., and Gel Form B, stable below 15° C.—and a condition of equilibrium at intermediate temperatures represented by the formula

Sol Form A $\rightleftarrows$ Gel Form B.

Gelatin in the highest concentrations (50 grams per 100 cc.) does not form a gel at 35° C. as it exists entirely in the sol form. At and below 15° C. a minimum quantity, 0.6 grams per 100 cc., is necessary to form the "standard gel" which was marked by the resistance of the movements of an air bubble in the polariscope tube. This concentration of gelatin suffers a total change of 0.80°, in rotation between 35° and 15° when the standard gel is produced. In higher concentrations this same change of 0.80°, corresponding to the production of 0.60 gram of Form B, results in the production of the standard gel. The maximum temperatures at which any concentration can produce a gel is conditioned, therefore, by the existence of this amount in equilibrium. The "melting temperatures" become identical with maximum gelation temperatures when sufficient time is given for equilibrium to be reached.

When gelatin is cooled rapidly from 35° to 20°, 19° or 15° in polariscopic tubes and the changing rotation followed with time,

* Communicated by the Chief of the Bureau.

[1] Published in *Jour. Amer. Chem. Soc.*, v. 41, 1919, p. 135.

it is found that the reaction is bimolecular, showing that the laws of mass action apply to a colloid like gelatin even when in the gel form in which most of the readings were made.

Following up the relation indicated, it was found that two molecules of Sol Form A were in equilibrium with one molecule of Gel, Form B, according to the formula

$$k\,(a-x)^2 = k^1\,x$$

Considering the change from the Sol Form A to the Gel Form B as bimolecular and further that a definite amount of the latter forms the standard gel, a formula was derived which permits the calculation of the time necessary for the production of gel in different concentrations at temperatures below 20° C. $(y^2d - yb)$ t = a constant, where y is the concentration in grams per 100 cc., d the total change in specific rotation observed between 35° and selected temperature, and b the change necessary to produce the standard gel. Experiment gave satisfactory results in agreement with the formula.

INFLAMMABILITY OF CARBONACEOUS DUSTS IN AIR AND IN ATMOSPHERES OF LOW OXYGEN CONTENT.[2]

By H. H. Brown.

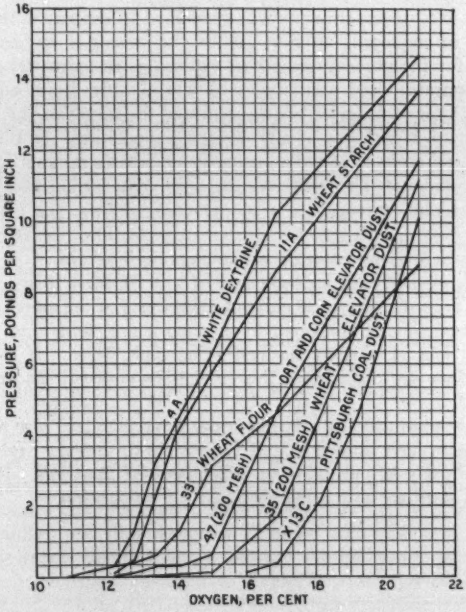
SEVERE property losses, in some cases attended by the destruction of human life, have occurred because of the fact that dusts from all materials which will burn are explosive. The Grain Dust Explosion Investigation Laboratory of the Bureau of Chemistry has investigated the explosibility of such dusts, with a view to ascertaining ways to reduce to a minimum the danger from dust explosions and fires in mills, grain elevators and cotton gins.

The relative inflammability of various dusts was determined in the laboratory, using a modification of the method devised by the Bureau of Mines for testing coal dust. Briefly, this method consists in forcing a cloud of dust (75 milligrams), which will pass through a 200-mesh screen, against a platinum-covered heating element, placed in the centre of a round glass globe with a

[2] Brown, H. H.: "Inflammability of Carbonaceous Dusts," *J. Ind. Eng. Chem.*, 9 (1917), 269. Brown, H. H., and Clement, J. K.: "Inflammability of Carbonaceous Dusts in Atmospheres of Low Oxygen Content," *J. Ind. Eng. Chem.*, 9 (1917), 347.

capacity of approximately 1400 cubic centimeters. The pressure produced by the ignition of the dust was measured by a steam pressure gauge.

The results obtained from a number of tests conducted in this way indicate that the pressure (expressed as pounds per square inch) generated by the ignition of several different types of dust



varies from 17.5 in the case of lycopodium and 15.2 for yellow corn dust from the first break in dry milling, through 13.2 for wheat starch, 11.3 for rice starch and 10.1 for Pittsburgh standard coal dust, to 3.2 for potato starch and 1.1 for gelatin dust from an elevator. Obviously, the dusts tested are highly inflammable, so that a cloud of any one of them suspended in the air forms a dangerous condition.

In the laboratory tests on the inflammability of coal dust, oxygen was employed to blow the cloud of dust against the heating coil, thus creating an atmosphere containing a greater amount of oxygen than is present in ordinary air. The pressures thus obtained exceed those secured when air alone is used. Conversely, lower pressures are shown when the surrounding air is deficient in oxygen.

A series of experiments was conducted to determine the possibility of employing an inert gas, or one lacking in oxygen, as a means for the prevention of dust explosions in industrial plants. The apparatus used was similar to that already described, with the addition of a device which permitted the filling of the explosion chamber with gas of any desired composition. In this way five typical dusts were tested, using gas mixtures ranging in composition from 16.9 per cent. oxygen, 4 per cent. carbon dioxid, and 79.1 per cent. nitrogen to 10.9 per cent. oxygen, 9.2 per cent. carbon dioxid, and 79.9 per cent. nitrogen. The results of this test are clearly shown in the accompanying diagram.

It is evident that an explosion of any of these dusts, which may be regarded as typical carbonaceous dusts of the more inflammable varieties, cannot occur in an atmosphere containing 12 per cent. or less of oxygen, the rest being inert gases. If elevator dusts alone are considered, this limit is extended to 14 or 14½ per cent.

Tests conducted on a larger scale, using standard size milling machinery, have shown that it is possible to prevent explosions in these units by means of an atmosphere of inert gas. Results of such tests are now being prepared for publication.

NOTES FROM THE RESEARCH LABORATORY WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY.*

AUTOGRAPHIC MEASUREMENTS OF THE QUENCHING POWER OF LIQUIDS.

By Norman B. Pilling.

[ABSTRACT.]

THE method which has been followed in this work involved the measurement of the rate of cooling of a small metallic cylinder quenched from a certain fixed temperature in the desired quenching medium, the latter being maintained at various temperatures. The temperature within the cylinder was measured with a small insulated platinum thermocouple, the hot junction of which was in good thermal contact with the bottom of an axial hole in the cylinder; the initial temperature of quenching was measured with a potentiometer, and subsequent temperature changes taking place during quenching were measured with a calibrated Enithoven galvanometer and recorded photographically upon a rotating film. Time intervals were also impressed upon the photographic record through suitable connections with a seconds pendulum.

It was not found feasible to use a steel cylinder for a heat reservoir, as the quantity of heat liberated at the transformation temperature was both variable and great enough to mask the temperature changes due to heat abstraction by the quenching liquid alone. An alloy composed of nickel with 5 per cent. silicon met the requirements suitably and had the additional advantage of being extremely resistant to oxidation, thus permitting the same standard to be used repeatedly, avoiding uncertain conditions due to small variations in mass and position of the thermo-element. The standard cylinder was 50 mm. long, 6 mm. diameter and weighed 11.6 grams.

A number of oils and aqueous solutions have been examined through a considerable range of temperature, and the results indicate the comparative stability of quenching power maintained

* Communicated by the Engineer in charge.

by oils at elevated temperatures as compared with the profound effect which temperature has with aqueous solutions in general upon their ability to absorb heat rapidly, due to changes in the mechanism of heat absorption. As an example, the ratio of the quenching power of water at the freezing point to that at the boiling point, taking the quenching power as proportional to the cooling velocity of the standard cylinder at 700° C., is 1 :20.

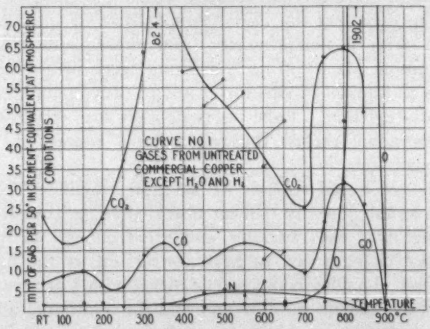
A more extended report on this subject will be published shortly elsewhere.

GASES FROM COPPER.

By H. M. Ryder.

[ABSTRACT.]

IN the course of some work concerning certain of the physical properties of copper, it was necessary to determine gases which could be removed from copper upon heating in vacuum. The

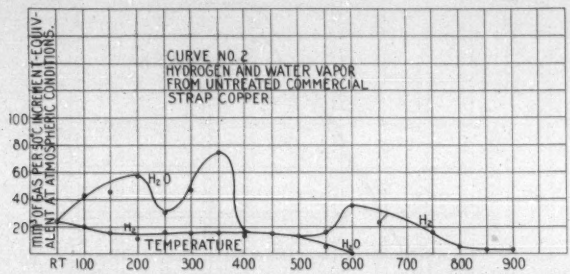


copper here used was annealed rolled strap containing .05 per cent. Cu_2 and .025 cm. x .244 cm. x 214 cm. long. This weighed 5 grams approximately and its volume was 1.31 c.c. This was placed in an apparatus developed for this work,[1] and was heated by the passage of an electric current, its temperature being determined by resistance changes. The gas removed was collected, out of contact with the copper, for 12 hour periods, the temperature of

[1] *J. Am. Chem. Soc.*, xl, 1656, Nov., 1918.

the specimen being increased 50° C. immediately after the removal of each sample.

The accompanying curves, plotted for each gas between quantity increment (per 50° rise) and the temperature, show the effect of temperature on the rate of evolution of the various gases. The maximum in the CO_2 curve at 350° C. is probably a property of the gas, since this is present in curves obtained similarly for a number of steels, irons, glasses and for porcelain. It might be possible to vary the shape of this curve by varying the time interval, but the time periods would have to be increased enormously to produce an appreciable change, since most of the gas shown for each point came off during the first half hour after bringing the temperature to the value shown.



The release of the large quantity of oxygen at 800° C. is due to the decomposition of Cu_2O. Sufficient evidence to establish this point will be presented later.

The maximum in the hydrogen curve at 600° C. is due to the fact that copper becomes permeable to hydrogen at this temperature.

THE MEASUREMENT OF LOW TEMPERATURES WITH THERMOCOUPLES.

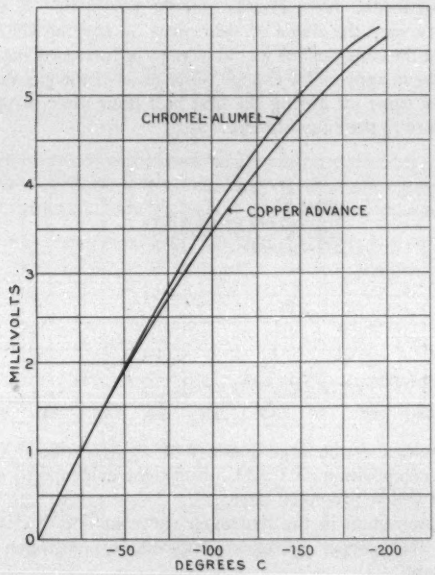
By Thomas Spooner.

[ABSTRACT.]

IN connection with some recent investigations, it was necessary to measure temperatures below 0° C. For this purpose thermocouples were the most convenient to use. It was known that

copper advance couples were satisfactory for temperatures down to liquid air values, but it was thought that Hoskin's thermocouple alloys, which go under the trade name of chromel-alumel, might be more satisfactory, as they give nearly a straight line calibration at temperatures above 0° C.

FIG. 1.



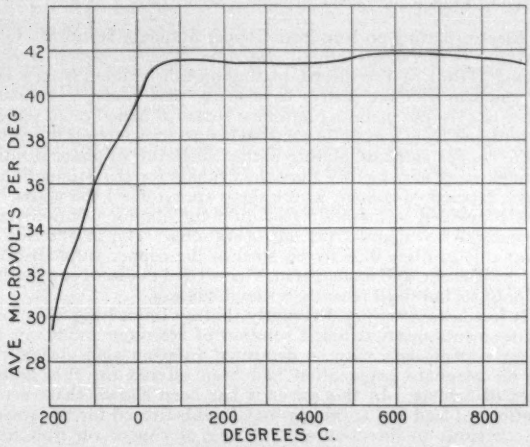
Thermocouple calibrations.

In order to investigate the thermal e.m.f. of the chromel-alumel material at low temperatures, a copper advance couple with its cold junction in ice water was first checked at the freezing point of mercury, at the sublimation point of CO_2 snow and at the temperature of boiling oxygen. These tests gave the following formula for the copper advance couple:

$$e = .03959t + .00004582t^2 - .0000000556t^3.$$

The copper advance couple and the chromel-alumel couple were inserted in holes in an iron cylinder which was then placed in a thermos bottle. Liquid air was poured into the bottle until the iron block reached the temperature of the liquid air. The block was then allowed to warm slowly in the thermos bottle and readings were taken of the e.m.f.'s of the two couples. Fig 1 gives the calibration of the two couples and Fig. 2 the average microvolts per degree between 0° C. and the given temperature

FIG. 2.



Chromel-alumel thermocouple.

from +900° C. to −190°. The high temperature values were obtained by calibration against a standardized platinum-platinum rhodium couple.

It will be noted from Fig. 2 that the microvolts drop off very rapidly below 0° C. and that the chromel-alumel couples show no appreciable advantages over the copper advance at low temperatures.

Big Ordnance Project Abandoned. ANON. (*Arms and the Man*, vol. lxv, No. 26, p. 504, March 22, 1919.)—The Neville Island ordnance project is to be entirely abandoned within the next few months. The buildings which have been erected there will eventually be torn down and the island restored to its original owners. The Neville Island project as originally planned by the Ordnance Department was one of the largest single undertakings of the war. Its estimated cost was $150,000,000, and in size and capacity it was to be larger than either the Krupp Works at Essen or the Creusot Works in France. It was planned with a capacity sufficient to produce fifteen 14-inch, 50-calibre rifles per month, and forty thousand 14-inch and 16-inch projectiles per month. One hundred and sixty-five of these immense rifles were to be turned out in time to be transported to France and on the firing line before May 1 of next year.

Electro-plating on Iron from Copper Sulphate Solution. O. P. WATTS. (*Proceedings of the American Electrochemical Society*, April 3-5, 1919.)—For electro-plating on iron or steel from a copper sulphate solution, platers have in the past found it necessary either to give the metal a preliminary coat of nickel or to plate it with copper from a cyanide solution before transferring the object to the copper sulphate plating bath. Since the sulphate solution is much more satisfactory than the cyanide for the production of heavy deposits of copper, where these are required the plater has been compelled to maintain two different plating solutions, and to perform two distinct plating operations. The desirability of being able to plate directly on steel in the copper sulphate solution is apparent, and many persons have tried to discover a method of doing so, but until recently without success.

It has been discovered recently that by immersing iron for a few moments in an acidified solution of arsenious oxide, an adherent copper-plate may be deposited from an acid electrolyte, but no adequate explanation had been offered for this unique effect of arsenic. In this paper it has been shown that certain solutions of lead and antimony may be substituted for the arsenic dip, previous to direct-current plating of copper on iron from copper sulphate.

It appears to be impossible to obtain a perfect plate on iron from solutions of bismuth chloride by the usual methods of electro-plating; but use of the arsenic or antimony dip is attended with the same successes as in copper plating.

The successful substitution of solutions of antimony and lead for arsenic, and the application of these dips to plating on iron with bismuth, show that the beneficial effect of the arsenic dip is not due to a property peculiar to arsenic alone, but is the result of coating the iron with a metal whose potential in acid solutions is so near to that of copper that it is possible to deposit a good copper plate upon it, yet whose potential is not so far below iron that it will deposit on iron in a powdery, non-adherent form.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, March 19, 1919.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 19, 1919.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 3.

Reports of progress were presented by the Committee on Library and the Committee on Science and the Arts.

Mr. Eric A. Lof, Electrical Engineer, General Electric Company, Schenectady, New York, presented a paper on "Hydro-electric Developments." The speaker described the recent advances made in hydro-electric installations, and gave detailed accounts of the operations of the power plants recently erected in the United States and Canada. The water-wheel driven generators, as well as the electrical apparatus which is necessary to complete the equipment of hydro-electric stations were fully described. The subject was illustrated by lantern slides.

After a brief discussion in which the Chairman, Mr. Crisfield, and others participated, the thanks of the meeting were extended to the speaker.

Adjourned.

GEORGE A. HOADLEY,
Secretary Pro Tem.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, March 5, 1919.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 5, 1919.

MR. BENJAMIN FRANKLIN *in the Chair.*

The following reports were presented for first reading:

No. 2729: Simplex Fluid Meter.

No. 2730: Monroe Calculating Machine. Advisory.

On the recommendation of the Sub-Committee on Literature, the following awards were made for papers in the JOURNAL, 1918:

No. 2736: The Edward Longstreth Medal of Merit to Dr. Joshua J. Skinner, of the Laboratory of Soil Fertility of the Department of Agriculture, Washington, D. C., for his paper entitled "Soil Aldehydes," described by the Sub-Committee as a valuable contribution to the science of agricultural chemistry.

No. 2737: Edward Longstreth Medals of Merit to Dr. Herbert E. Ives, Dr. E. F. Kingsbury and Dr. E. Karrer, all of the Physical Laboratory of the United Gas Improvement Company, Philadelphia, Pa., for their paper entitled "The Physics of the Welsbach Mantle," described by the Sub-Committee as affording a definite indication of both the limitations and possible efficiency of the Welsbach Mantle.

No. 2738: The Edward Longstreth Medal of Merit to Mr. Richard B. Moore, of the United States Bureau of Mines, for his biography and review of the work of Sir William Ramsay, described by the Sub-Committee as a most lucid and informing exposition of the great chemist's life and work.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, March 12, 1919.)

RESIDENT.

MR. J. HOWARD PEW, President, Sun Oil Company and Sun Oil Company, Finance Building, Philadelphia, Pennsylvania.

NON-RESIDENT.

MR. OLAF ANDERSEN, Geologist, Mineralogical Institute, Kristiania, Norway.

MR. HUGH SEPTIMUS GORDON, Mining Engineer, 10 Nevill Court, London, E. C. 4, England.

CHANGES OF ADDRESS.

LIEUTENANT JAMES W. COTTRELL, P. O. Box 302, Hammonton, New Jersey.
CAPTAIN HENRY M. ELLIOTT, Wardman Park Inn, Washington, District of Columbia.
DR. MILTON W. FRANKLIN, Remy Electric Company, Andersen, Indiana.
LIEUTENANT A. H. GFRÖRER, The Automatic Transportation Company, 2933–65 Main Street, Buffalo, New York.
MR. OTTO LUYTIES, Sharon Springs, New York.
LIEUTENANT THOMAS S. MARTIN, 3D, 710 North 41st Street, Philadelphia, Pennsylvania.
MR. W. A. PATTON, Radnor, Pennsylvania.
LIEUTENANT CHARLES E. RICHARDSON, in care of International Coal Products Corporation, 581 Broad Street, Newark, New Jersey.
MR. DWIGHT P. ROBINSON, 49 East 52d Street, New York City, New York.
LIEUTENANT COLONEL W. C. SPRUANCE, 2507 West 17th Street, Wilmington, Delaware.
MR. FRANK A. STANLEY, East Auburn, California.
MR. JOHN STONE STONE, 68 Montague Street, Brooklyn, New York.

NECROLOGY.

James Douglas, LL.D., was born in Quebec, Canada, on November 4, 1837, and died on June 25, 1918. He received his education in his native city and in Germany and Scotland. He was a graduate of Queens and Laval Universities, Canada.

He became interested in mining and metallurgy through his connection with the Harvey Hill mines and other mining properties in Lower Canada. In 1875 he removed to Phoenixville, Pennsylvania, to take charge of the metallurgical operations of the Chemical Copper Company. Five years later he visited Arizona and became active in copper mining. He spent many years in developing mining lands in Arizona, Mexico and New Mexico, and took an active part in the promotion of railroad enterprises throughout these States. For a number of years Doctor Douglas was president of the El Paso and Southwestern Railroad Company, which operates over a thousand miles of standard-gauge road.

His literary labors include "Canadian Independence," "Quebec in the Seventeenth Century," "New England and New France," "Journal and Reminiscences of James Douglas." He contributed many articles to the technical press, and delivered a number of lectures and addresses, including a series of the Cantor Lectures before the Royal Society of Arts of London.

Doctor Douglas was a member of many scientific societies, both in the United States and in Europe. He was twice president of the American Institute of Mining Engineers, and was also a member of the Board of Trustees of the American Museum of Natural History. He was the recipient of the Gold Medal of the Institution of Mining and Metallurgy, and in 1915 was awarded the John Fritz Medal. In 1899 he received the Honorary Degree of Doctor of Laws from McGill University. Doctor Douglas became a member of The Franklin Institute in 1899.

Lewis Sharpe Ware, for nearly forty-two years a member of The Franklin Institute, died in Paris, France, on December 20, 1918.

Mr Ware was born in Philadelphia on June 18, 1851, son of Lewis S. and Elizabeth W. Roberts Ware. He was educated at the Hill School, Pottstown, Pennsylvania, and in 1875 graduated from the École Centrale in Paris. He then became interested in the problem of sugar beet cultivation and the manufacture of beet sugar and made an extensive study of the beet fields of Europe. In 1874 he shipped several tons of beet seeds to the United States for gratuitous distribution among the farmers. Soon after this he returned to his native city, and in 1879 began the publication of *The Sugar Beet*, which was devoted solely to problems connected with the cultivation of this important plant. This publication appeared uninterruptedly for more than thirty years.

Mr Ware became a member of The Franklin Institute on March 16, 1877, and was appointed a member of the Committee on Library in 1880. He was intensely interested in the work of this Committee, and took an active part in the management of the library until 1888. About this time he took up his permanent residence in Paris, and only visited the United States at infrequent intervals. He obtained quarters in the French capital and began the collection of books, pamphlets and magazines relating to sugar and the sugar industry. The library soon began to grow beyond his expectations, and he found it necessary to secure the services of a librarian. In 1911 the work of cataloging had sufficiently advanced to make it possible to issue a list of the French section. This volume numbers 340 pages and contains over 3400 entries.

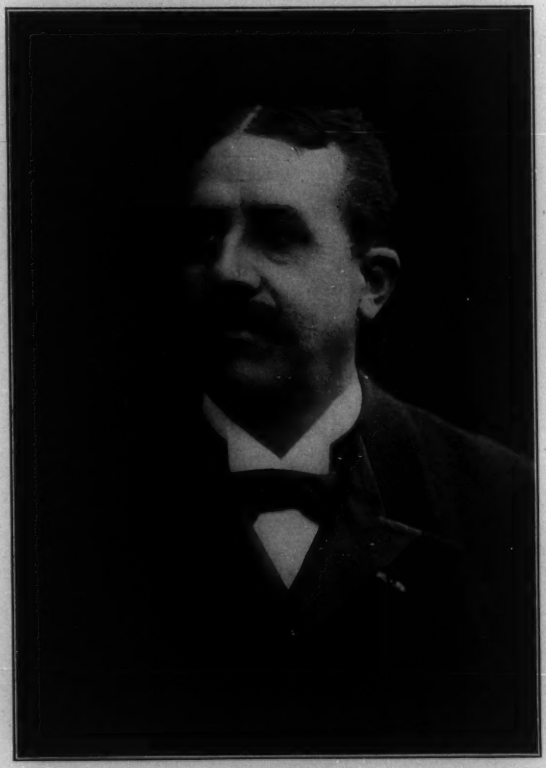
During the three decades which have elapsed he has been able to gather together the world's publications on sugar and related subjects, consisting of all printed documents, in all languages, from the earliest times to and including the year 1918. This library, to which he has devoted his best energies during a great part of his life, now becomes the property of The Franklin Institute. He has directed that it shall be deposited in the Institute's library and shall be known as the Ware Sugar Library. A sufficient sum of money has also been provided, the income from which is to be applied to the purchase of new books, and to the care, maintenance and preservation of the entire collection.

Mr Ware represented the United States at the Paris Exposition of 1889 and again in 1900; he was United States Commissioner-General to the International Exposition at Liege, Belgium, 1905.

His many decorations include Chevalier Merite Agricole, 1893; Chevalier de la Legion d'Honneur, 1901; Officier Ordre de Leopold; Commandeur Etoile Noire; Officier de l'Instruction Publique.

He was a member of the American Philosophical Society; the Association des Chimistes, Paris; Association des Anciens Élèves de École Centrale, and the Ingenieurs Coloniaux.

His works include "The Sugar Beet," 1880; "Study of the Various Sources of Sugar," 1881; "Production, Requirements and Selection of Sugar Beet Seed," 1896; "Sugar Beet Seed," 1898; "Cattle Feeding with Sugar Beets, Sugar, Molasses, etc.," 1902; "Beet Sugar, Manufacturing and Refining" (2 vols.), 1907.



LEWIS S. WARE
1851–1918

John Sellers Bancroft, member of the Franklin Institute since 1865, died January 29, 1919, after a lingering illness. He was the son of Edward Bancroft and Mary Sellers Bancroft and was born in Providence, R. I., September 12, 1843. His father, who will be remembered as the inventor of the "Ball and Socket Hanger," operated a machine shop in Providence, R. I., in partnership with his brother-in-law, William Sellers, making lathes, planers, drill presses and specializing in shafting and mill gearing.

In 1848 Bancroft & Sellers removed to Philadelphia and in 1855 were located at Sixteenth and Hamilton Streets. On the death of Edward Bancroft, John Sellers, Jr., was admitted to partnership and the firm name was changed to William Sellers & Co.

John Sellers Bancroft graduated from the Central High School in 1861 and became an indentured apprentice in the machine shop of his uncles in that year. He applied himself so assiduously to his duties and developed so much ability that he was made a gang foreman in his nineteenth year and upon completing his apprenticeship, in 1864, was appointed foreman of the machine shop. Two years later, at the age of twenty-three, he became general foreman of the whole establishment, including foundry and smith shop.

He was admitted to partnership in 1873 and upon the incorporation of the firm, in 1886, he was elected a director and general manager. In 1902 he resigned to associate himself with the Lanston Monotype Machine Company as mechanical engineer and manager and later as vice-president and treasurer.

He became a member of the American Society of Mechanical Engineers in 1880, was a manager 1909–1911, and a vice-president 1915–1917.

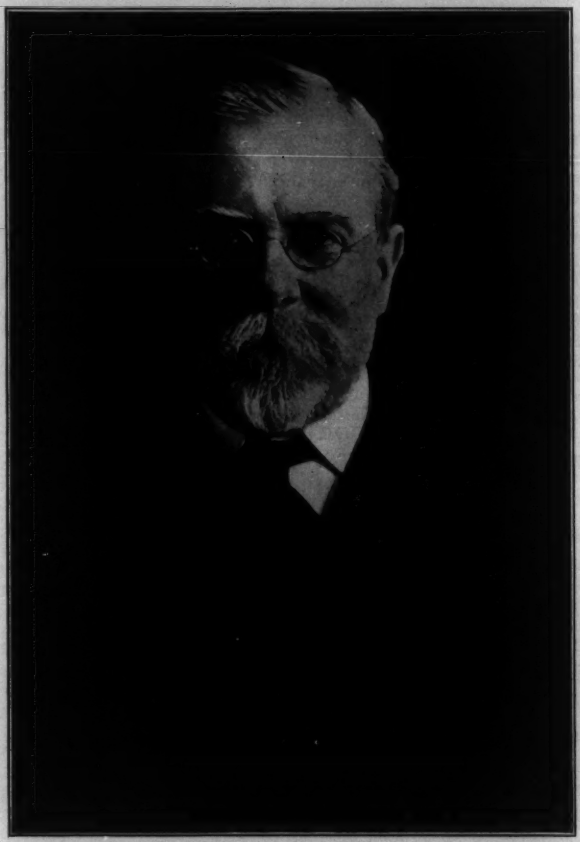
During his long connection with the Franklin Institute he does not seem to have held any office; but he was much interested in its work and served on many committees.

About 1861 his firm introduced into the United States the Giffard Injector for feeding boilers. This was not only a new device but its manufacture required the development of a proper system of methods, tools and fixtures; and in establishing and developing this work, Mr. Bancroft was largely instrumental. Later he concerned himself earnestly with the improvement of the instrument and conducted or directed the tests and experiments upon which the improvements were based.

Perhaps the most conspicuous achievement of his later life was the perfection of the Lanston Monotype Machine. It came to him scarcely more than an ingenious mechanical toy, frail, unreliable and difficult to construct. He superintended its redesign to facilitate its manufacture, located one by one its weak spots, devised corrections, made improvements and developed a system of manufacture which produced a thoroughly practicable substantial machine of much greater scope and capacity than the original; and from a partial failure he evolved a great commercial and mechanical success.

Mr. Bancroft was a mechanic of unusual ability and a fertile, versatile inventor, as is attested by the large number and great variety of patents which bear his name. He had high mechanical ideals and strove for the best in method and workmanship. As an executive officer he was a strict disciplinarian, was careful and thorough, and gave close attention to details.

COLEMAN SELLERS, JR.



JOHN SELLERS BANCROFT
1843–1919

Mr. Charles A. Brinley, 247 South 16th Street, Philadelphia, Pennsylvania.

Dr. Charles F. Himes, Carlisle, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

BLANCHARD, A. H., ed.—American Highway Engineers' Handbook. 1919.
DANA, GORHAM.—Automatic Sprinkler Protection. 1919.
GRABAU, A. W.—Principles of Stratigraphy. 1918.
GRIFFITHS, EZER.—Methods of Measuring Temperature. 1918.
Industrial Arts Index. Vol. 6. 1918.
JACKSON, J. F. A., comp.—Philadelphia Year Book. 1919.
MCCOLLUM, E. V.—The Newer Knowledge of Nutrition. 1919.
PERKIN, A. G., and EVEREST, A. E.—Natural Organic Colouring Matters. 1918.
Photograms of the Year. 1918.
SCHUSTER, A., and SHIPLEY, A. E.—Britain's Heritage of Science. 1918.
SCOTT, W. W., ed.—Standard Methods of Chemical Analysis. 1918.
STEWART, A. W.—Recent Advances in Organic Chemistry. 1918.

BOOK NOTICES.

BEVERAGES AND THEIR ADULTERATION, ORIGIN, COMPOSITION, MANUFACTURE. NATURAL, ARTIFICIAL, FERMENTED, DISTILLED, ALKALOIDAL AND FRUIT JUICES. By Harvey W. Wiley, M.D. 408 pages and index, illustrations, 8vo. Philadelphia, P. Blakiston's Son & Company, 1919. Price, $3.50 net.

Food analysts and public health authorities will greet with pleasure the appearance of this work. Few persons are as well qualified as the author to speak with authority on the subject, now especially important in view of the drastic methods that have been adopted to control all habit-forming beverages. Before passing to a review of the text, it is proper to say that the book is an excellent specimen of printing, and is exceptionally free from typographical errors. Those that have been noted are trifling, but Doctor Wiley accidentally "hustero-proterizes"—as Carlyle would say—on page 128, when he states that Charles II failed in his "campaign against coffee, and it was taken up by Oliver Cromwell."

The work is characteristically "Wileyesque." Its author may, indeed, be considered the Roosevelt of American Food Chemistry; earnest and aggressive in what he believes to be the right, fearless in defending his views, whether antagonized by those in high station or low; intensely dogmatic, but sometimes unable to see clearly the other side of the question at issue. Doctor Wiley, however, always speaks from thorough and detailed information; the late ex-President was much more of a generalizer.

The work is not a manual of analysis. Except in the section on "Tea," methods of detecting adulterations are practically lacking. Much space is given to the manufacture of the more important beverages, with elaborate

details as to the source and character of commercial wines and brandies, together with a number of formulas for mixed drinks. A matter of particular interest is the adulteration of whisky, a subject upon which there is widespread ignorance and consequent error. In discussing the question of prohibition, no statement is more frequently made by the anti-prohibitionists than that where the licensed saloon is suppressed, highly adulterated and poisonous liquors are sold in the "blind tigers," "speak-easies," etc. An extensive correspondence that I had some years ago with the food analysts of the several States showed no evidence of such adulterations, and Doctor Wiley's book confirms this view, for under the head of adulterations of whisky no mention is made of any poisonous ingredients having been found in it. As the subject is of great present practical importance, it will be worth while to note briefly what is said about it in the book. As is well known to all food chemists, Doctor Wiley took a very active part in the discussion of the question, "What is Whisky?" which arose mainly over the interpretation of a clause in the Federal Food and Drug Act. The question of the poisonous nature of the additions was not prominent, for it was conceded that they were not any more harmful than the alcohol, and, indeed, in most cases not harmful at all. An effort was made to limit the term "whisky" to a distillate from the fermented mash of certain grains, and especially to declare that if the so-called "silent spirit" was added with or without harmless coloring matters—such as prune juice or burnt sugar —the article should be designated "compound," and not merely "blended." Space does not permit even outlining the arguments and developments in the case, but the result was that President Roosevelt and Attorney-General Bonaparte took the extreme view, but President Taft and Solicitor-General Bowers practically reversed these decisions. Doctor Wiley summarizes the present practise of the Federal authorities as follows: "The regulations of the Bureau of Internal Revenue, which control the marking and branding of distilled spirits at the present time (1918), are based on the above opinion, but go much further in validating misbranding and adulterations." One turns, therefore, with especial interest to the paragraphs on whisky adulterations to see what has been the result of this alleged "letting-up" in favor of the trade. Turning to the special item, "Adulterations of Whisky" (page 326), we read: "The adulteration of distilled liquors in all parts of the world has been continuous and extensive. Perhaps there is no other country where adulteration has reached such proportions as in our own." Three types are then enumerated. *First:* Selling raw spirits; that is, freshly distilled whiskies, under guise of age by means of artificial coloring. Burnt sugar (caramel) is the only artificial coloring mentioned in this paragraph, but allusion is made to hastening the coloring process by keeping the whisky hot while in a charred cask. *Second:* Substitution of whisky by a spirit rectified more or less completely, and from which the substances that give to whisky its character have been entirely or in part removed. *Third:* The refilling of bottles which have contained genuine whisky with an adulterated article (presumably adulterated by one of the methods just described) which is still sold under the same name.

This is all. No reference to "stock-in-trade" cries of the liquor element, "rot-gut," "kill-at-forty-paces," "Jersey-lightning." Singularly, there seems to be no reference to the possible use of rectified methyl alcohol as an adul-

terant; the title is not even in the index. That there is no mention of strychnin and fish-berries need not astonish, for these additions are practically unknown now even if they ever occurred.

Sixty-four pages are devoted to potable waters, including methods of purification, and standards of chemical and bacterial purity. In view of the thoroughness with which these subjects are now presented in special manuals, much of this section seems unnecessary. The author accidentally falls into a contradiction when, in the introduction (page xiii), water is classed as purely condimental; that is, having little or no food value, while on page 1 of the body of the text it is termed an indispensable food. Of the forty-two illustrations, two are of leaves that may be used for adulteration of tea, and twenty-three of scenes in wine-making.

The work contains a large amount of information on one of the most important topics in public hygiene. In the chapter on water there is a discussion of the divining-rod, and scattered throughout there is considerable general literature. Thomas Jefferson's views on the wine-excise are quoted, and many extracts given from old books and essays. Occasionally the author "drops into poetry," or, rather, doggerel.

It is evident that Doctor Wiley has poured his soul into the book, and on almost every page we see the results, both tangible and psychologic, of his long, active, efficient work in connection with the efforts of the authorities to improve the standards of foods and beverages and to protect the mass of the people from fraud and harm. He began work in the days of the primordial chaos of food regulation in this country, and for many years was one of the principal determinants in the investigations. It would be idle to pretend that the present condition is not one of some degree of disappointment, for every one familiar with existing conditions as revealed by the records of our courts, Federal and State, knows that the war against food-fraud is far from won. We can, therefore, easily understand why the book shows the author's emotional reaction to the abuses of which he has seen so much, and against some of which he has valiantly but vainly contended. He can indeed say of the course of American food control,

"quæque ipse miserrima vidi,
et quorum pars magna fui."

HENRY LEFFMANN.

TREATISE ON APPLIED ANALYTICAL CHEMISTRY: METHODS AND STANDARDS FOR THE CHEMICAL ANALYSIS OF THE PRINCIPAL INDUSTRIAL AND FOOD PRODUCTS. By Professor Vittorio Villavecchia, assisted by several collaborators. Translated by Thomas H. Cope, B.Sc., University of Birmingham. Volume II, 528 pages, contents and index, illustrations, 8vo. Philadelphia, P. Blakiston's Son & Company, 1918. Price, $6.

The first volume of this work was reviewed in this JOURNAL some months ago, and much of what was there stated can be stated of the present volume, which completes the work. The book is excellently printed, the translation well done, the arrangement of the subject matter convenient, and the processes given commendable. The present volume covers many important and difficult subjects, among which are meat, milk, flour and related articles, sugars, fermented

beverages, rubber and substitutes, tanning materials, inks and coloring matters. Extensive treatment is given of the last-named group, and elaborate tables for the detection of colors under several conditions are presented.

American work seems to have but little interest to the author. Examination of the bibliographic references shows that out of a total of about one hundred and fifty, only four can be considered American. Forty-eight are to German publications and forty-four to Italian. The remainder are to French and British authorities.

The chapter on "Beer" has been re-written by the translator. Under whisky no mention is made of the possible admixture with burnt sugar or prune juice.

The style is concise and clear, and the work will be of great value to the practical analyst. HENRY LEFFMANN.

SURFACE TENSION AND SURFACE ENERGY, AND THEIR INFLUENCE ON CHEMICAL PHENOMENA. By R. S. Willows, M.A., D.Sc., and E. Hatschek. Second edition, 112 pages, contents and index, 21 illustrations, 12mo. Philadelphia, P. Blakiston's Son & Company, 1919. Price, $1.50 net.

In preparing this second edition, the authors have extended considerably the field to be covered, and have added much matter which they tell us has been suggested by the questions from students and readers. An entirely new chapter (VI) is specially devoted to complex phenomena, among which may be mentioned "Emulsions," "Electrical Theory of Dyeing," "Theory of Tanning," "Origin of Thunderstorms," "Flotation Processes." In the last case, only one process is discussed—that of the "Minerals Separation Company." It appears, however, that much remains to be determined concerning the exact theory of these now much-used processes, for the authors say (pages 104–5): "No general theory of the process has, however, resulted so far, and we can, therefore, only roughly indicate the factors which come into play. The selective adsorption of the oils by the sulphids is a fact which in the present state of our knowledge we have simply to accept." HENRY LEFFMANN.

ANNUAIRE POUR L'AN 1919, PAR LE BUREAU DES LONGITUDES. AVEC DES NOTICES SCIENTIFIQUES. About 700 pages, 14 figures, 5 celestial charts in colors, 3 magnetic charts, 16mo, paper bound. Paris, Gauthier-Villars et Cie, 1919. Price, three francs.

The publication of this annual was instituted by the National Convention on the 7th of Messidor an 3, less than a year after the close of the Terror. The first edition appeared in 1796, and it has been issued regularly to this day. The roar of guns for over four years in "Flanders Fields" has not broken its course. The text is of the same general type as those of former issues and will not need specific mention, but at the request of the publishers the reviewer notes the titles and authors of two original papers that appear in this issue:

Figures d'équilibre relatif d'un liquide homogène en rotation, dont les éléments s'attirent suivant la loi de Newton, by P. Appell.

La détermination interférentielle des diamètres des astres, by Maurice Hamy. HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

U. S. Provost Marshal General: Second report to the Secretary of War on the operations of the Selective Service System to December 20, 1918. 607 pages, 8vo. Washington, Government Printing Office, 1919.

U. S. Bureau of Mines: Bulletin 172. Abstract of Current Decisions on Mines and Mining reported from January to May, 1918, by J. W. Thompson. 160 pages, 8vo. Technical paper 96. Fume and Other Losses in Condensing Quicksilver from Furnace Gases, by L. H. Duschak and C. N. Schuette. 29 pages, illustrations, 8vo. Technical paper 191. Central Station Heating; Its Economic Features with Reference to Community Service, by John C. White. 23 pages, illustrations, 8vo. Technical paper 215. Accidents at Metallurgical Works in the United States During the Calendar Year 1917, compiled by Albert H. Fay. 23 pages, 8vo. Technical paper 217. Saving Coal in Steam Power Plants. 8 pages illustrations, 8vo. Washington, Government Printing Office, 1918–1919.

Ontario Bureau of Mines: Twenty-seventh Annual Report, 1918, part I. 265 pages, illustrations, plates, maps, 8vo. Toronto, King's printer, 1918.

A Quick Method of Coping Steel Beams. F. W. HARTH. (*The Iron Age*, vol. ciii, No. 11, p. 694, March 13, 1919.)—A new steel beam method, as employed by a large Pittsburgh structural concern, is not alone interesting but also economical. "Coping" is the term applied to the cutting-away of a beam at the end to conform to the contour of the beam against which it is framed. The old method of coping steel beams is very expensive, involving considerable time and labor, the cost averaging $5 per ton beam weight. A very heavy machine, costing perhaps several thousand dollars is used for this work. It is sometimes located in a building by itself, the motive power being hydraulic. As the machine is stationary, the work must be brought to it, which involves considerable handling of quite heavy pieces.

With the new method, the oxyacetylene flame is used. The work need not be moved in performing the operation, and the cut can be made wherever the stock may be; many of the beams are coped on the freight car just prior to shipment. The cost of coping by the acetylene torch, which entails so much less labor and handling, is rarely more than $1 per ton beam weight, or just 20 per cent. of the cost of machine coping. In order to make it possible to employ the gas flame at any point in a fabricating plant, a pipe-line is run underground with top lines radiating from it. The gas is supplied from a central station and piped to the various points where required most.

CURRENT TOPICS.

The Audion Amplifier. ANON. (*Telegraph and Telephone Age*, vol. xxxvii, No. 5, March 1, 1919.)—For more than twenty years, telephone engineers had sought in vain a repeater or amplifying relay, which would be at once extremely sensitive, free from delicate and frequent adjustments, and yet would amplify every modulation of the human voice without distortion. Without such a relay, a telephone at that time was limited to a few hundred miles. This problem of the telephone relay had baffled all the numberless inventors and engineers in the telephone industry. It was an elusive will-o'-the-wisp which looked so simple, and yet defied their most praiseworthy efforts. So keen did the search become and so hopeless seemed the solution, that an eastern telephone company in the nineties offered one million dollars for a successful telephone relay. The prize was never awarded, or claimed. Almost without exception these telephone engineers and inventors attacked the problem from the same angle. They saw one method which afforded a solution. That was to associate in some manner the elements of the well-known telephone receiver and telephone transmitter or carbon microphone. The method was a mechanical one which always in the final analysis failed.

We are indebted to the "wireless" for the revolution in ideas telephonic which alone enables one to talk from San Francisco to New York. In 1902, Dr. Lee de Forest, in the course of his experiments with wireless detectors, discovered that a heated gas was "sensitive" to weak "wireless" waves, and could constitute a new detector for use in radio-telegraphy. In 1903–04 he made over this principle a genuinely practical detector, possessing a sensitiveness far exceeding that of any previously known wireless receiver. He found that when this device, altogether new to the telephone field, was properly connected in the line between a transmitter and a receiver, the audion amplified the voice currents, giving a reproduction of perfect fidelity without a trace of lag or distortion. The audion amplifier was patented in 1907, but it was not till 1912 that the inventor deemed it sufficiently developed to bring it to the attention of the engineering staff of the American Telephone and Telegraph Company. In 1913 announcements were made that the long-dreamed-of transcontinental line was to become a reality.

The audion amplifier consists of a small incandescent lamp bulb exhausted of air, which contains, in addition to the usual filament, two thin plates of nickel about one-eighth of an inch from the filament on each side. Between the filament and the plates are two pieces of nickel wire bent grid-shaped. The incoming current, to be repeated and amplified, is conducted to the "grid" wire. The outgoing line is connected, one terminal to the plates, the other to the filament. In this circuit is found a battery. A separate battery lights the filament to incandescence. The heated gas becomes then a conductor of the local current from the battery which can pass from the cold plates to the hot filament. That is, negatively charged "carrier," "ions" or "thermions," as they are termed, speed in invisible streams of almost infinite tenuity from filament plates, passing in their migration through the spaces between the wires of the grids. The slightest electrical potential, or charge of electricity impressed upon these grids from the incoming telephonic currents, deflects or retards some of these minute carriers of negative electricity. This effect is always proportional to the cause, so that the current changes produced in the outgoing or "plate" circuit are exactly similar to those current changes or electric charges upon the grid which produced them. In other words, a unit electrical charge delivered upon the "grid" produces a deflection or stoppage of six to ten unit electrical charges passing from the filament to the plates.

The De Forest audion is to-day receiving wireless messages in New York, and at the great naval station at Arlington, Va., from San Francisco; Nauen, Germany; Paris, France, and from the radio stations in the Pacific Ocean. Transoceanic telephony by submarine cable, with numerous Pupin coils and the audion amplifier is theoretically possible; commercially an utter impossibility. The cost of such a cable would be prohibitive. Transoceanic wireless telephony, however, is to-day almost within our reach.

Production of Hydrogen and Water Glass by the Silicol Process. ANON. (*Chemical and Metallurgical Engineering*, vol. xx, No. 6, p. 289, March 15, 1919.)—Several years ago George F. Jaubert described the military methods in use at that time for the production of hydrogen, among which the reduction of water by silicon was of chief importance for military purposes, such as for dirigibles, etc. Siemens and Schuckert were the original investigators and worked out a process for the production of hydrogen from the reaction:

$$Si + 2NaOH + H_2O = Na_2SiO_3 + 2H_2$$

Initially steam was employed, but later it was found that the heat of solution of the caustic was sufficient to start the reaction and that it would maintain itself thereafter. The process was a chemical success, but, due to the high price of silicon, was not economical.

In order to reduce the costs of the pure silicon, Captain H. Lelarge substituted silicon alloys in the process, successfully operating the reaction with a silicon iron containing as little as 18 per cent. silicon. However, the 50 to 80 per cent. ferrosilicons were much preferable. *Engineering*, in its January 24 issue, gives a description of one of the British Admiralty hydrogen gas plants, the production of which in peace times may be utilized in oil refining by the water-glass method and hardening by hydrogenation, offering an outlet for both the sodium silicate and the hydrogen at obnormally low costs.

The plant operates the silicol process, which consists in the decomposition of silicon alloys obtained in the electric furnace, such as ferro- or mangano-silicon, or even silicospiegel, by a concentrated solution of caustic soda (35 per cent. to 40 per cent. of NaOH). In the silicol process, the silicon alloys are made to act on a caustic alkali solution having a high boiling-point, the object being to retain in the solution itself all the heat generated by the reaction in the combination of the silicon with the alkali, thus doing away with all outside heating.

The Rôle of the Catalyst. ANON. (*The Lancet*, through *Scientific American Supplement*, vol. lxxxvii, No. 2254, p. 164, March 15, 1919.)—Chemists long ago discovered the peculiar action of a third party in promoting chemical interaction. It may function equally in the relatively cold or under conditions of high temperature. The remarkable behavior of catalysts in the human body at its normal temperature illustrates the importance of their action in promoting healthy nutrition, which depends upon the complete chemical assimilation of food substances. An early example of catalysis is in the use of spongy platinum, in the presence of which the union of a mixture of hydrogen and oxygen takes place at such a speed that ignition results. The most remarkable catalyst of all is water, without which, it has been shown, combustion or oxidation is impossible.

We have much yet to learn as to the nature of the action of the accessory factors in food—for convenience called vitamines—which serve as antineuritic and antiscorbutic agents. It is conceivable that, in a chemical sense, they act as catalysts—that is,

as a third party, rendering the potentialities available for the maintenance and growth of the organism. It is known, at all events, that they occur in quite minute proportions, in spite of which they prove to be essential to growth. When we consider the very remarkable results produced in great industrial processes by the agency of the merest trace of a third party, the catalyst, our views are strengthened as to the importance of a certain factor in however minute quantity. There is good reason for suggesting that the vitamines are catalysts just as are the enzymes, whose action in many respects resembles that of inorganic catalysts, particularly in the colloidal state. Dr. G. G. Henderson, in his recent valuable treatise, "Catalysis in Industrial Chemistry" (Longmans, 1919), says that the term catalysis is now generally used to designate those chemical changes of which the progress is modified by the presence of a foreign substance, and he further points out that it has for a long time been known that the velocity of many chemical reactions, which take place very slowly if the reacting substances alone are present in the system, is greatly increased by the addition of certain substances which have the same composition after the change has been completed as at the beginning, and therefore appear to influence the course of the reaction without taking any definite stoicheiometric part. This definition would appear to include as catalysts all necessary food factors having no direct nutritive value themselves, but serving as promoters of a nutrient consummation.

The application of catalysts in industrial operations is growing very rapidly in importance, and the behavior in many respects of the catalysts employed shows a curious parallel to well-known physiological phenomena. Traces of arsenic, mercury, sulphur, hydrocyanic acid "poison" in many cases the catalysts' activities, and there are also negative catalysts which inhibit the action of positive catalysts, not by "poisoning" them, but by neutralizing their potentialities as acid does an alkali. The advances made and the vista opened up by the study of catalytic action, though confined largely to industrial processes, should persuade biologists, as well as biological chemists—we see no dividing line between these two schools of workers—to accept a cue which followed may lead to results of immeasurable importance in the study of life processes.

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*Deceased.

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Contributing members, if eligible, under the non-resident clause, on making request therefor, may be transferred to the non-resident class by vote of the Board of Managers, and are required to pay Five Dollars annually.

ASSOCIATE MEMBERS.—Associate members are accorded all the privileges of The Institute, except the right to vote or hold office, upon the payment of annual dues of Five Dollars. This class of membership is limited to persons between the ages of seventeen and twenty-five years. Upon reaching the age limit they become eligible to the other classes of membership.

RESIGNATIONS *must be made in writing, and dues must be paid to the date of resignation.*

For further information and membership application blanks address the SECRETARY of THE INSTITUTE.

THE FRANKLIN INSTITUTE AWARDS

THE JOHN SCOTT LEGACY MEDAL AND PREMIUM

THE City of Philadelphia holds in trust under the legacy of John Scott, of Edinburgh, a sum of money the interest of which is to be used for the encouragement of "ingenious men and women who make useful inventions." **The legacy provides for the distribution of a Medal, inscribed "To the Most Deserving," and Money Premium in the sum of $20 to such persons whose inventions shall merit the same.** The examination of the inventions submitted for the Medal and Premium has been delegated by the Board of Directors of City Trusts, of the City of Philadelphia, to THE FRANKLIN INSTITUTE, and THE INSTITUTE, under the competent assistance of its Committee on Science and the Arts, undertakes to make investigations free of charge and to recommend for the award all meritorious inventions.

Applications should be addressed to the Secretary of THE FRANKLIN INSTITUTE, from whom all information relative thereto may be obtained.

Pursuant to the regulations for the award of the John Scott Legacy Medal and Premium, THE FRANKLIN INSTITUTE, of the State of Pennsylvania, has under consideration favorable reports upon the applications advertised in this JOURNAL. Any objection to the proposed awards, based on evidence of lack of originality or merit of the invention, should be communicated to the Secretary of THE INSTITUTE within three months of the date of notice.

AWARDS BY THE INSTITUTE

The following awards are made by, or on the recommendation of, The Franklin Institute:

The Franklin Medal (Gold Medal and Diploma).—This medal is awarded annually from the Franklin Medal Fund, founded January 1, 1914, by Samuel Insull, Esq., to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

The Elliott Cresson Medal (Gold Medal and Diploma).—This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

The Howard N. Potts Medal (Gold Medal and Diploma).—This medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products of superior excellence or utilizing important principles; and for papers of especial merit that have been presented to the Institute and published in its JOURNAL.

The Edward Longstreth Medal of Merit (Silver Medal and Diploma).—This medal, with a money premium when the accumulated interest of the fund permits, is awarded for meritorious work in science or the arts; including papers relating to such subjects originally read before the Institute, and papers presented to the Institute and published in its JOURNAL. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance, or for meritorious papers presented to the Institute and published in its JOURNAL.

The Certificate of Merit.—A Certificate of Merit is awarded to persons adjudged worthy thereof for their inventions, discoveries or productions.

The John Scott Legacy Medal and Premium (Bronze Medal, Diploma, and Premium of $20.00).—In addition to the foregoing awards by the Institute, the Board of Directors of City Trusts of the City of Philadelphia awards this medal and premium upon the recommendation of the Institute in accordance with the terms of the deed of gift restricting it "to ingenious men and women who make useful inventions."

The Boyden Premium.—Uriah A. Boyden, Esq., of Boston, Mass., has deposited with THE FRANKLIN INSTITUTE the sum of one thousand dollars, to be awarded as premium to "any resident of North America who shall determine by experiment whether all rays of light, and other physical rays, are or are not transmitted with the same velocity."

For further information relating to these awards apply to the Secretary of the Institute.